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BULLETIN
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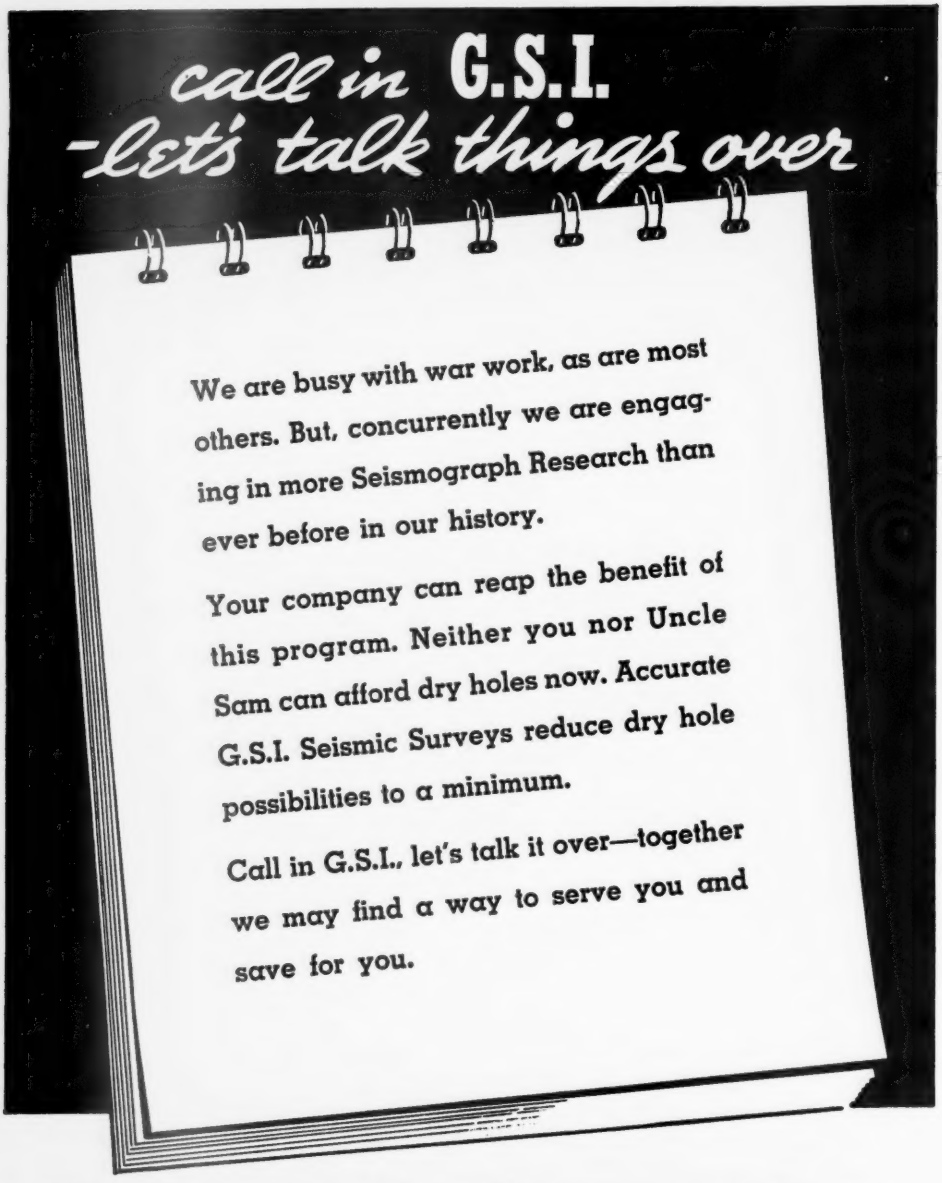
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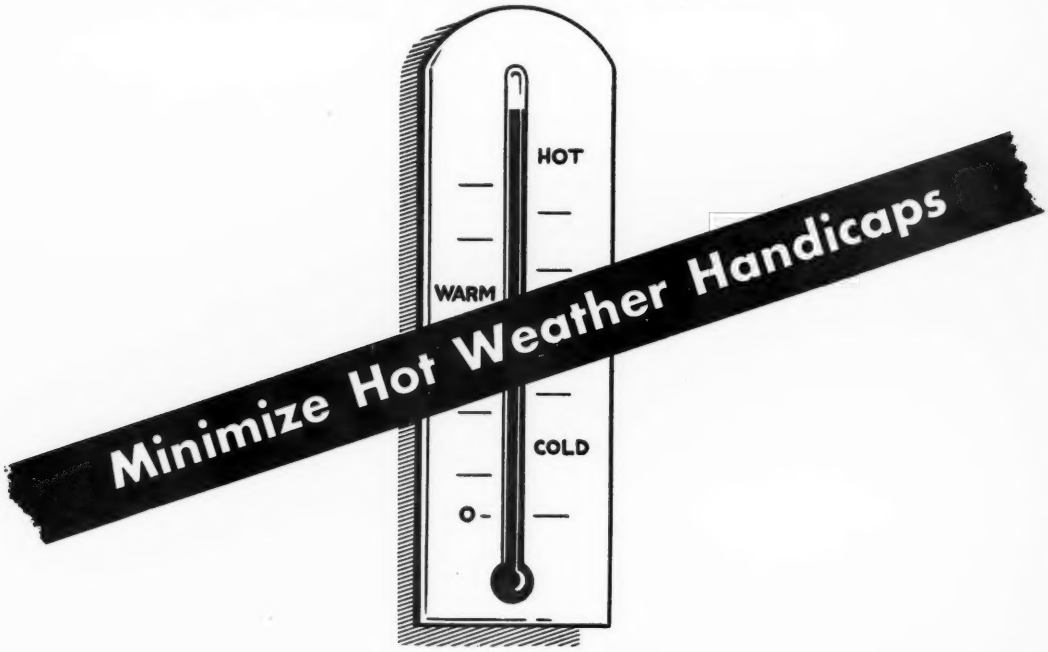

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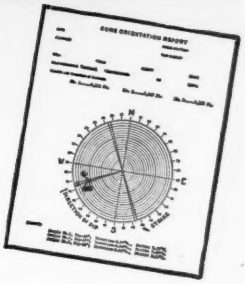

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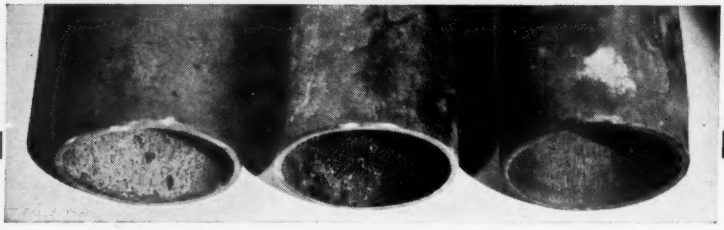

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BULLETIN
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AUGUST, 1942

OIL-FIELD WATERS OF MONTANA PLAINS[1]

JAMES G. CRAWFORD[2]
Casper, Wyoming

ABSTRACT

Tabular and graphic analyses of waters from the oil- and gas-producing zones of Montana are presented and discussed.

Montana group waters, with the exception of those waters associated with gas, are dilute to moderately dilute solutions of sodium salts, sulphate being present in many waters to a considerable extent. Colorado group waters in the Sweetgrass arch fields are moderately concentrated to concentrated solutions of sodium chloride; elsewhere these waters are less saline and moderately dilute. Kootenai waters resemble Colorado waters to some extent, but are ordinarily more alkaline. Ellis waters are alkaline, moderately concentrated, and contain hydrogen sulphide in appreciable amounts. The "Quadrant" formation yields large flows of water in which the sulphates of calcium and magnesium dominate the chemical system. Tensleep waters of central and southern Montana are similar to "Quadrant" waters of north-central Montana. Madison waters of primary characteristics are found in the Sweetgrass arch fields, and secondary characteristics are present in the Madison waters of the north-central and central fields.

The analyses indicate that all the oil- and gas-field waters of Montana have been considerably modified by the infiltration of meteoric waters.

INTRODUCTION

This largely factual paper presents in tabular and graphic form 279 analyses of water samples from borings at widely separated localities on the Great Plains of Montana; it describes the similarities and dissimilarities of waters from the same and different formations; it postulates the sources of the waters, the direction of migration, and describes local structural and stratigraphic conditions controlling accumulation. The paper is similar to one on Wyoming,[3] both papers being the result of regional studies carried out for the purpose of identifying lithologic zones penetrated in borings by means of water analyses and to acquire additional data that would permit more general and accurate application of this procedure throughout the Rocky Mountain states.

The analyses were made in the chemical laboratory of the United States Geological Survey, which was moved from Midwest, Wyoming, to Casper,

[1] Published by permission of the director of the Geological Survey. Manuscript received, November 28, 1941.

[2] Associate petroleum chemist, Geological Survey, United States Department of the Interior, 305 Federal Building, Casper.

[3] James G. Crawford, "Oil-Field Waters of Wyoming and Their Relation to Geological Formations," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 7 (July, 1940), pp. 1214–1329.

Wyoming, in 1940. Well depths, formation intervals, and descriptive matter are from records in the Survey office at Casper.

The term "Quadrant" herein designates the Upper Mississippian and early Pennsylvanian beds in central Montana that were formerly assigned to the Quadrant formation but which are believed to be older than true Quadrant at its type locality.

ACKNOWLEDGMENTS

The writer is indebted to the following members of the United States Geological Survey: Herman Stabler, H. J. Duncan, W. M. Peden, H. H. Perrigo, and R. M. Larsen for both general and specific criticism; to J. H. Thompson for preparing the illustrations; and to C. E. Dobbin and C. E. Erdmann who generously contributed their knowledge and data on the geology of Montana.

Classification of Oil-Field Waters

The well known Palmer[4] system of classification has been followed, as it emphasizes the geochemical relationship of natural waters. Palmer groups those radicles that are chemically related or geologically associated, so that all waters are divided into four classes: (1) primary salinity—alkalies with the strong acids; (2) secondary salinity—excess alkaline earths with strong acids; (3) primary alkalinity—excess alkalies with weak acids; and (4) secondary alkalinity—alkaline earths with excess of weak acids. Secondary salinity and primary alkalinity are incompatible, and both can not be present in the same water.

Primary salinity is common to all waters. A water high in primary alkalinity is a good solvent of siliceous rocks. A secondary saline water is ordinarily derived from marine deposits, is permanently hard, and is illustrated by the so-called "gyp" waters of the western states. A water in which secondary alkalinity predominates is temporarily hard and is ordinarily derived from and contributes to calcareous beds.

General Character of Oil-Field Waters in the Rocky Mountain Region

The oil-field waters of the Rocky Mountain region are in general much less concentrated than those of other regions. Water of less than 500 parts per million total solids has been found associated with oil in Wyoming, and water of more than 20,000 parts per million is exceptional. For this reason, the terminology used in this paper is as follows: dilute, from 200 to 1,000 parts per million; moderately dilute, from 1,000 to 3,000 parts per million; moderately concentrated, from 3,000 to 8,000 parts per million; concentrated, from 8,000 to 20,000 parts per million; highly concentrated, from 20,000 parts per million.

[4] Chase Palmer, "The Geochemical Interpretation of Water Analyses," *U. S. Geol. Survey Bull. 479* (1911).

It has been pointed out[5] that concentration is a measure of water movement in a sand, and is controlled chiefly by the physical characteristics of the strata. Where dilute water is found in a structure, it generally indicates a freedom of flow which has swept away oil that may have once accumulated there. The few exceptions to this rule are dilute, artesian waters in the base of a sand that have been forced upward into contact with oil, or have migrated upward through faults or fractures, and subsequently trapped with oil.

A moderately concentrated to concentrated water is ordinarily found in structural traps which have not been thoroughly flushed by circulating ground water. The presence of a concentrated water under these conditions indicates only better chances of oil or gas being present.

It is difficult, however, to set arbitrarily a concentration limit below which the chances of oil or gas accumulation are *nil*, in Rocky Mountain structures, because certain exceptional conditions may be present in the structures. However, if the concentration of the water is below 1,000 parts per million, it is very doubtful if a commercial oil or gas pool exists. If the concentration is between 1,000 and 2,000 parts per million, a commercial pool is improbable, but possible, and if it exceeds 2,000 parts per million a commercial pool is possible and probable.

The oil-field waters of Montana vary in concentration from dilute artesian water of 300 parts per million to at least one highly concentrated water containing 32,000 parts per million. The average oil-field water in Montana contains 1,500 to 15,000 parts per million total solids. Almost all waters contain a little calcium and magnesium, but these radicles do not dominate in the waters above the "Quadrant" formation. In the "Quadrant" and below, calcium and magnesium ordinarily predominate. The partial and even total softening of waters in formations younger than "Quadrant" results in most cases from contact with bentonite which removes calcium and magnesium by base-exchange action.

General Character of Producing Zones

The oil and gas fields of Montana lie in the plains east of the Rocky Mountains and north of the Big Horn and Pryor mountains (Fig. 1). Several uplifts characterize the plains, for example, the Sweetgrass Hills, the Bearpaw Mountains, the Little Rocky Mountains, the Highwood Mountains, the Moccasin Mountains, the Judith Mountains, the Little Belt Mountains, and the Big Snowy Mountains. Five rivers drain the plains, namely, Marias River, Milk River, Missouri River, Musselshell River, and Yellowstone River, the Marias, Milk, Musselshell, and Yellowstone being important tributaries of the Missouri.

The largest and most productive oil and gas fields in Montana are in the Sweetgrass arch region, which contains the Cut Bank and Kevin-Sunburst fields.

[5] J. G. Crawford, *op. cit.*, p. 1317.

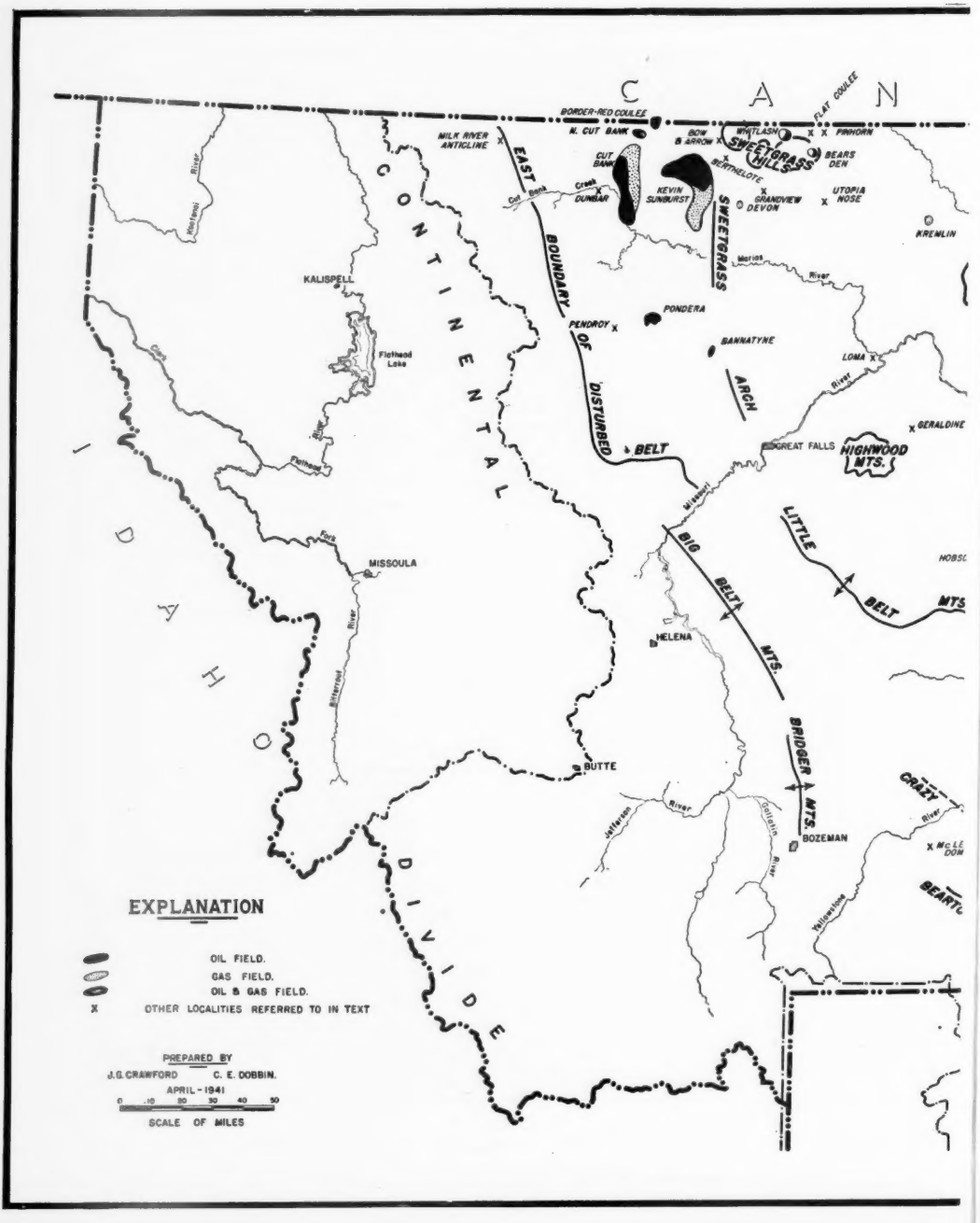
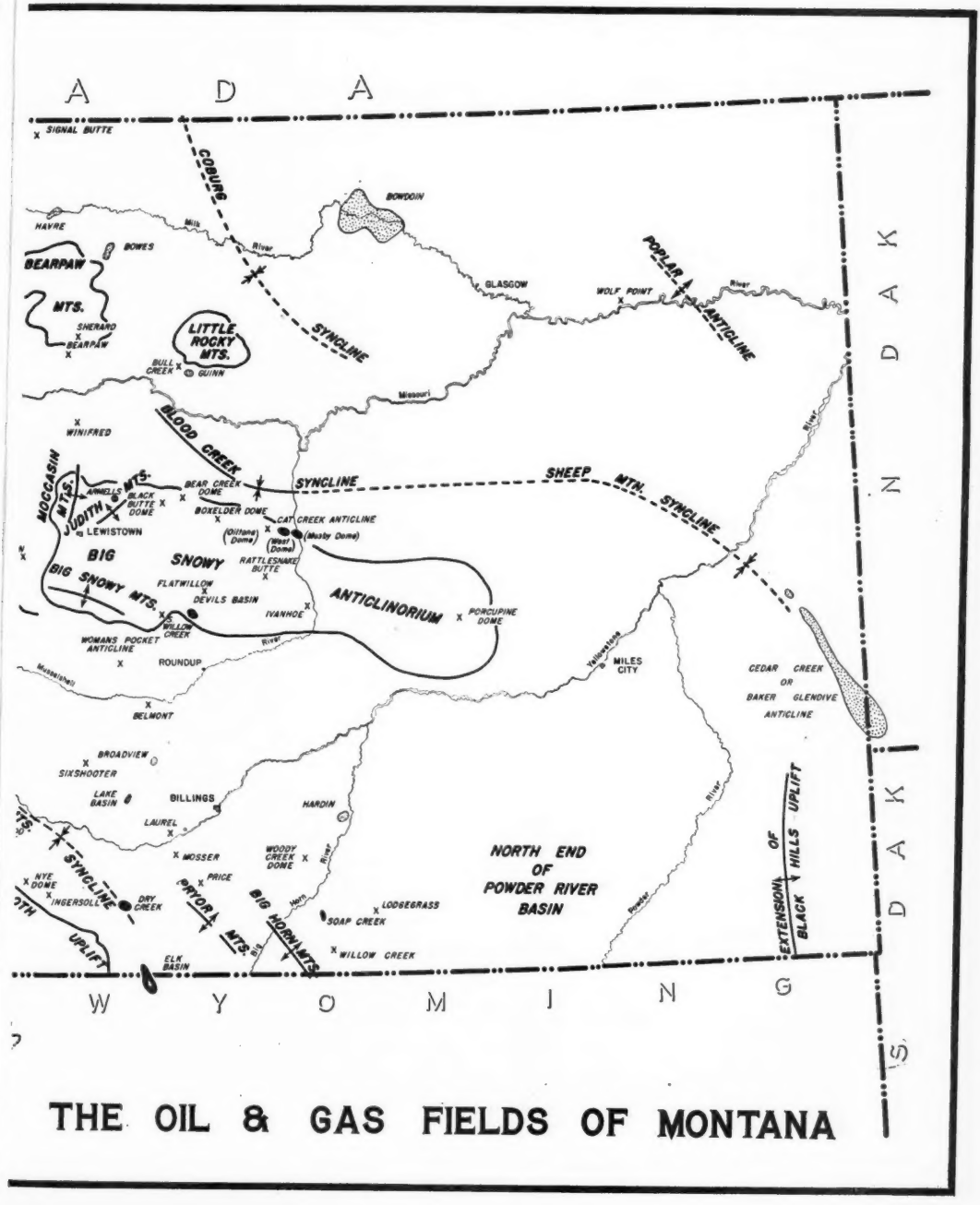

C A N
BORDER-RED COULEE
FLAT COULEE
N. CUT BANK
MILK RIVER ANTICLINE
CUT BANK
Cut Bank Creek
DUNBAR
BOW & ARROW
WHITLASH
SWEETGRASS HILLS
FINHORN
BEARS DEN
BERTHELOTE
KEVIN SUNBURST
GRANDVIEW DEVON
UTOPIA NOSE
KREMLIN
EAST BOUNDARY OF DISTURBED BELT
SWEETGRASS ARCH
Marias River
PONDERA
PENDROY
BANNATYNE
LOMA
GERALDINE
GREAT FALLS
HIGHWOOD MTS.
KALISPELL
Flathead River
Flathead Lake
CONTINENTAL DIVIDE
MISSOULA
Clark Fork
Blackfoot River
Missouri River
LITTLE BELT MTS.
BIG BELT MTS.
HELENA
BRIDGER MTS.
BUTTE
Jefferson River
Gallatin River
BOZEMAN
Yellowstone
CRAZY
BEARTU
IDAHO
EXPLANATION
OIL FIELD.
GAS FIELD.
OIL & GAS FIELD.
OTHER LOCALITIES REFERRED TO IN TEXT
PREPARED BY
J.G. CRAWFORD C. E. DOBBIN.
APRIL - 1941
0 10 20 30 40 50
SCALE OF MILES

FIG. 1



THE OIL & GAS FIELDS OF MONTANA

FIG. 1

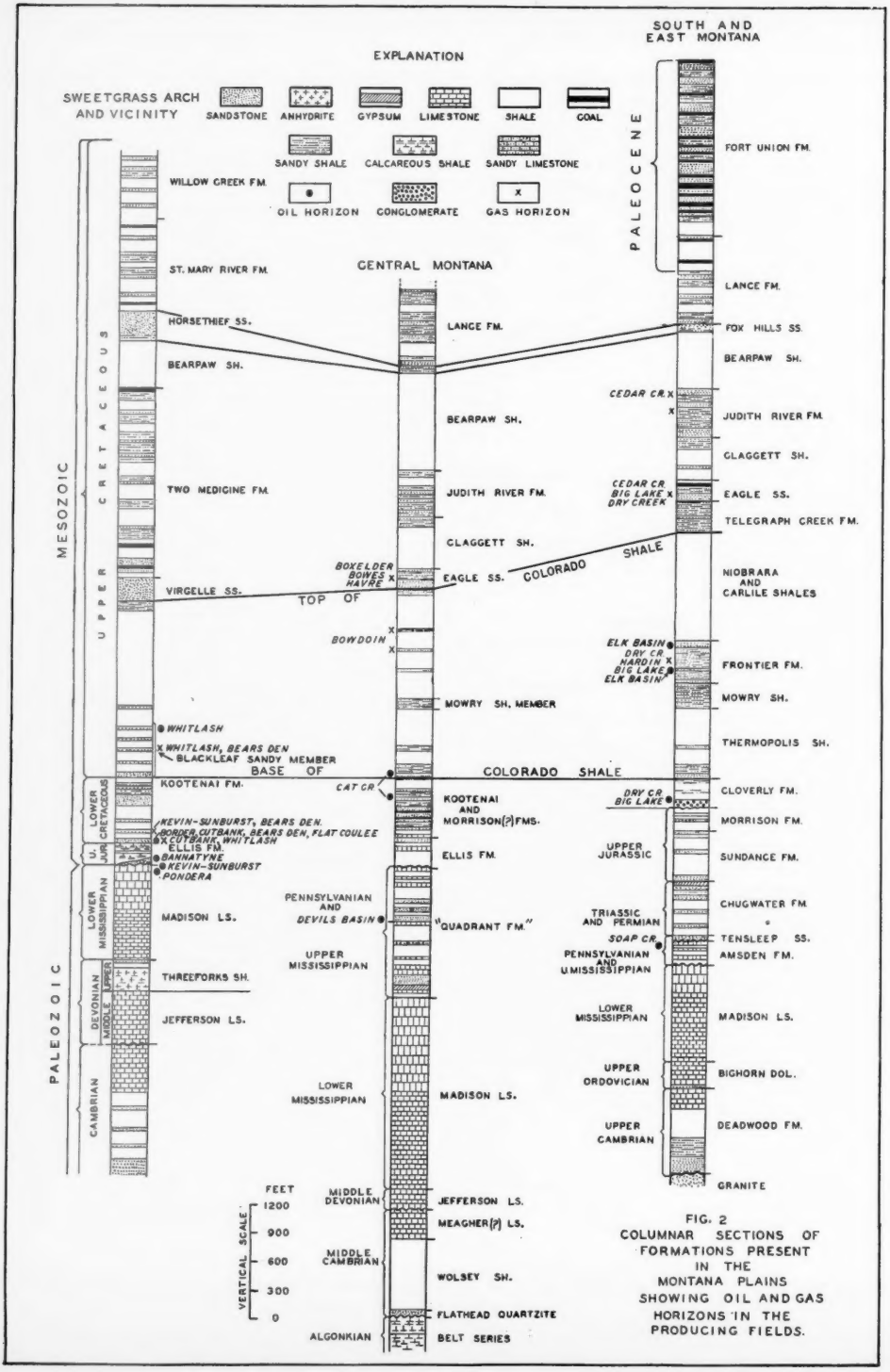


FIG. 2
COLUMNAR SECTIONS OF FORMATIONS PRESENT IN THE MONTANA PLAINS SHOWING OIL AND GAS HORIZONS IN THE PRODUCING FIELDS.

FIG. 2

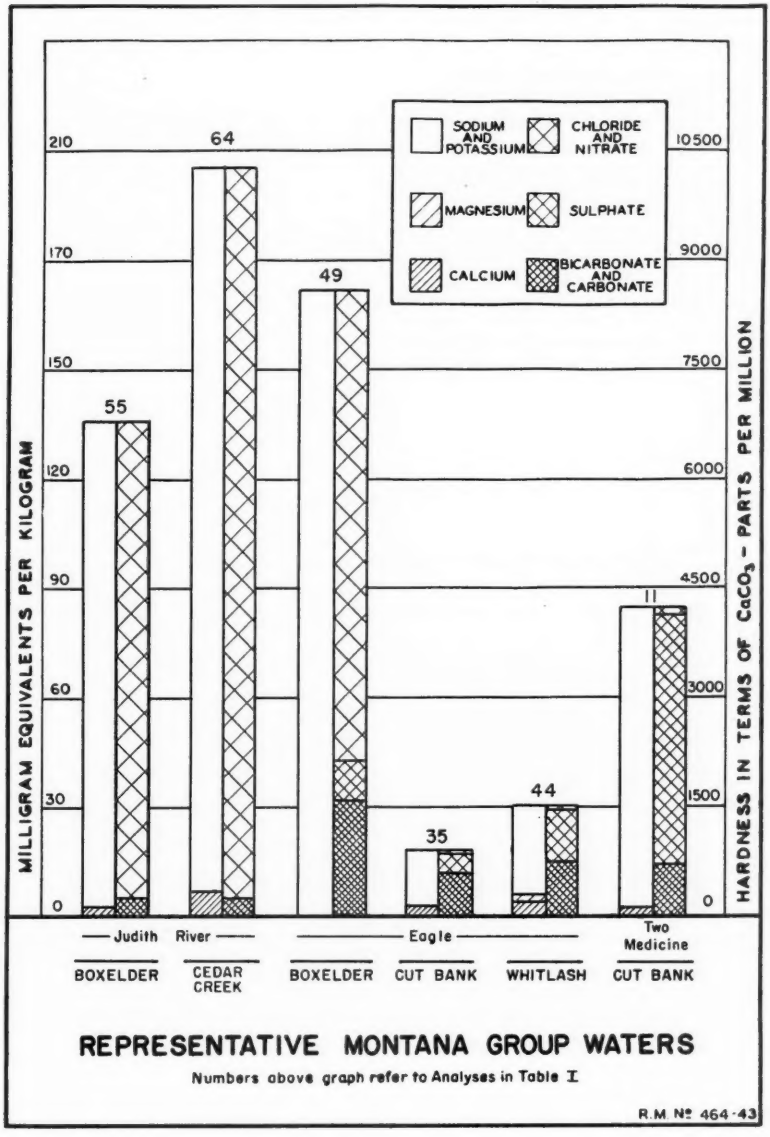

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
210
170
150
120
90
60
30
0
10500
9000
7500
6000
4500
3000
1500
0
64
55
49
35
44
11
Judith River
Eagle
Two Medicine
BOXELDER
CEDAR CREEK
BOXELDER
CUT BANK
WHITLASH
CUT BANK
REPRESENTATIVE MONTANA GROUP WATERS
Numbers above graph refer to Analyses in Table I
R.M. Nº 464-43

FIG. 3

TABLE I

Montana Group Waters

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS						PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
	TWO MEDICINE FORMATION WATERS:									SWEETGRASS ARCH FIELDS															
1	Milk River Anticline	1	NE 26	36N	12W	790	326	- -	- -	43	150	96	355	14.15	- -	- -	0.90	4.23	3.20	5.82	36.26	- - -	63.74	- - -	82.46	17.54
2	Cut Bank	2	NW 24	37N	5W	2,599	828	93	Tr	1,214	15	- -	913	36.01	4.64	- -	25.27	0.42	- - -	14.96	63.20	- - -	25.78	11.42	1.62	98.38
3	Cut Bank	1	NE 28	36N	5W	4,294	1,462	- -	- -	2,451	27	- -	720	63.59	- -	- -	51.03	0.76	- - -	11.80	81.44	- - -	18.56	- - -	1.47	98.53
4	Cut Bank	2	NW 15	35N	6W	3,431	1,162	19	- -	1,853	48	24	640	50.53	0.90	- -	38.79	1.35	0.80	10.49	78.04	- - -	20.20	1.76	3.36	96.64
5	Cut Bank	1	NE 15	35N	6W	3,509	1,073	52	55	1,852	133	Tr	700	46.66	2.60	4.52	38.56	3.75	- - -	11.47	78.68	- - -	8.08	13.24	8.87	91.13
6	Cut Bank	1	NE 14	35N	6W	8,142	2,375	171	121	4,807	109	- -	1,145	103.33	8.53	9.95	100.08	2.96	- - -	18.77	84.60	- - -	0.22	15.18	2.88	97.12
7	Cut Bank		14	35N	6W	6,858	2,036	185	Tr	4,523	103	6	31	88.55	9.23	- -	94.17	2.90	0.20	0.51	90.56	8.72	- - -	0.72	2.99	97.01
8	Cut Bank		27	36N	6W	3,204	1,076	15	- -	1,829	24	12	505	46.58	0.75	- -	38.08	0.68	0.40	8.27	83.72	- - -	16.70	1.58	1.75	98.24
9	Cut Bank	1	SW 1	35N	5W	2,303	844	- -	- -	932	52	Tr	965	36.70	- -	- -	19.41	1.47	- - -	15.82	56.90	- - -	43.10	- - -	7.03	92.97
10	Cut Bank	1	4	35N	5W	2,223	796	- -	- -	997	83	42	620	34.66	- -	- -	20.76	2.34	1.40	10.16	66.66	- - -	33.34	- - -	10.14	89.86
11	Cut Bank	1	NE 31	35N	5W	5,644	1,880	30	Tr	3,262	71	- -	815	81.77	1.50	- -	67.91	2.00	- - -	13.36	83.96	- - -	14.24	1.80	2.86	97.14
12	Cut Bank	- -	SE 13	34N	6W	3,155	1,159	- -	- -	1,193	229	222	715	50.42	- -	- -	24.84	6.46	7.40	11.72	62.08	- - -	37.92	- - -	20.68	79.32
13	Cut Bank	1	NE 26	34N	6W	1,384	498	25	Tr	495	22	- -	760	21.65	1.25	- -	9.50	0.62	- - -	12.78	44.20	- - -	50.34	5.46	15.36	84.64
14	Cut Bank	- -	13	33N	7W	920	187	38	75	329	70	- -	450	8.13	1.90	6.17	6.85	1.97	- - -	7.38	50.18	4.26	- - -	45.56	22.33	77.67
15	Cut Bank	- -	SE 13	33N	7W	1,024	391	Tr	- -	304	65	- -	535	16.94	- -	- -	6.35	1.83	- - -	8.76	48.28	- - -	51.72	- - -	22.36	77.64
16	Cut Bank	1	NW 10	33N	6W	815	255	51	Tr	255	38	- -	440	11.05	2.55	- -	5.31	1.07	- - -	7.22	46.90	- - -	34.34	18.76	16.75	83.25
17	Cut Bank	- -	NE 16	33N	6W	815	313	Tr	- -	229	54	Tr	445	13.58	- -	- -	4.76	1.52	- - -	7.30	45.24	- - -	53.76	- - -	24.20	75.80
18	Cut Bank	2	6	32N	5W	3,456	1,111	59	Tr	1,982	25	- -	568	48.33	2.95	- -	41.27	0.71	- - -	9.30	82.06	- - -	12.18	5.76	1.93	98.07
	TWO MEDICINE AND EAGLE MIXED WATERS:																									
19	Cut Bank	1	15	35N	6W	2,606	906	17	- -	1,193	157	6	665	39.52	0.85	- -	24.84	4.43	0.20	10.90	72.50	- - -	25.40	2.10	15.13	84.87
20	Cut Bank	1	27	35N	6W	2,132	702	69	- -	848	195	- -	660	30.53	3.44	- -	17.65	5.50	- - -	10.81	68.20	- - -	21.68	10.12	23.75	76.25
21	Cut Bank	1	SE 35	35N	6W	1,815	662	18	- -	535	289	- -	635	28.79	0.90	- -	11.14	8.15	- - -	10.40	64.98	- - -	31.06	3.96	42.26	57.74
22	Cut Bank	1	SW 1	35N	5W	2,141	870	- -	- -	1,046	48	Tr	870	37.82	- -	- -	22.51	1.35	- - -	14.26	62.70	- - -	37.30	- - -	5.65	94.35
23	Cut Bank	2	NW 11	34N	6W	1,540	592	- -	- -	604	27	Tr	645	25.78	- -	- -	14.44	0.75	- - -	10.67	59.00	- - -	41.00	- - -	5.02	94.98
24	Cut Bank	1	NW 14	34N	6W	2,027	748	- -	- -	803	162	Tr	550	32.10	- -	- -	16.72	4.57	- - -	10.81	66.32	- - -	33.68	- - -	21.47	78.53
25	Cut Bank	2	SW 14	34N	6W	1,914	708	- -	- -	605	137	50	560	30.81	- -	- -	14.47	3.85	1.67	10.81	59.50	- - -	40.50	- - -	21.08	78.92
26	Cut Bank	- -	14	34N	6W	1,791	617	43	- -	641	151	- -	690	26.76	2.15	- -	13.34	4.26	- - -	11.31	60.88	- - -	31.68	7.44	24.20	75.80
27	Cut Bank	2	SE 24	34N	6W	1,614	607	- -	- -	537	99	- -	755	26.34	- -	- -	11.18	2.79	- - -	12.37	53.04	- - -	46.96	- - -	10.67	80.01
28	Cut Bank	1	SW 25	34N	6W	1,711	616	- -	- -	622	79	90	660	27.66	- -	- -	12.95	2.23	1.67	10.81	54.88	- - -	45.12	- - -	14.69	85.31
29	Cut Bank	2	SE 2	33N	6W	1,449	545	- -	- -	454	129	37	575	23.74	- -	- -	9.45	3.64	1.23	9.42	55.14	- - -	44.86	- - -	27.82	72.18
30	Cut Bank	1	NE 20	33N	5W	1,430	538	- -	- -	467	96	34	620	23.40	- -	- -	9.73	2.71	0.80	10.16	53.16	- - -	46.84	- - -	21.78	78.22
31	Cut Bank	1	1	32N	6W	1,445	548	- -	- -	436	116	50	600	23.85	- -	- -	9.08	3.27	1.67	9.83	51.78	- - -	48.22	- - -	25.47	73.53
	EAGLE SANDSTONE WATERS:																									
32	Cut Bank	1	NW 23	37N	5W	992	379	- -	- -	117	27	72	665	16.49	- -	- -	2.43	0.76	2.40	10.90	19.34	- - -	80.66	- - -	23.79	76.21
33	Cut Bank	- -	24	36N	5W	644	254	- -	- -	152	22	Tr	440	11.00	- -	- -	3.16	0.62	- - -	7.22	34.36	- - -	65.64	- - -	16.39	83.61
34	Cut Bank	1	SW 26	35N	6W	992	396	- -	- -	265	14	Tr	665	16.80	- -	- -	5.51	0.39	- - -	10.90	35.12	- - -	64.88	- - -	6.61	93.39
35	Cut Bank	2	2	35N	5W	992	320	51	Tr	272	23	- -	645	14.33	2.55	- -	5.66	0.65	- - -	10.57	37.38	- - -	47.52	15.10	10.33	89.67
36	Cut Bank	1	NE 15	34N	6W	880	307	33	Tr	252	27	- -	560	13.36	1.65	- -	5.24	0.76	- - -	9.01	30.08	- - -	40.02	11.00	12.65	87.34
37	Cut Bank	1	- - -	33N	5W	1,068	206	83	52	449	15	- -	514	8.96	4.14	5.10	9.35	0.42	- - -	8.43	49.24	4.44	- - -	46.32	4.30	95.70
38	Cut Bank	- -	NW 22	33N	5W	953	143	86	78	350	28	- -	525	6.19	4.29	6.41	7.90	0.79	- - -	8.60	35.64	12.44	- - -	50.92	9.53	90.47
39	Cut Bank	1	SE 10	32N	5W	1,019	406	- -	- -	210	31	67	620	17.63	- -	- -	4.37	0.87	2.23	10.16	20.72	- - -	70.28	- - -	16.52	83.38
40	Border-Red Coulee	- -	NW 2	37N	4W	1,499	326	88	70	751	23	- -	490	14.16	4.39	5.76	15.63	0.65	- - -	8.03	58.24	8.74	- - -	33.02	4.00	96.00
41	Border-Red Coulee	- -	SW 2	37N	4W	1,183	219	93	69	546	10	- -	500	9.53	4.64	5.67	11.37	0.28	- - -	8.19	48.04	10.68	- - -	41.28	2.42	97.58
42	Round Lake	1	SE 28	36N	4W	1,101	420	- -	- -	348	11	24	605	18.27	- -	- -	7.24	0.31	0.80	9.92	41.32	- - -	58.68	- - -	4.12	95.88

TABLE I (Continued)
MONTANA GROUP WATERS

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
	EAGLE SANDSTONE WATERS:									SWEETGRASS HILLS NORTH CENTRAL and CENTRAL FIELDS																
43	Berthelote (Virgelle)	1	NE 25	36N	1E	381	40	58	34	68	6	- -	355	1.72	2.89	2.80	1.42	0.17	- - -	5.82	21.46	- - -	1.76	76.78	10.72	89.28
44	Whitlash (Glacial drift)	1	NE 26	37N	4E	1,764	541	63	29	686	12	- -	880	23.52	3.14	2.38	14.28	0.34	- - -	14.42	50.34	- - -	30.64	19.02	2.30	97.70
45	Pinhorn (Upper Eagle)	1	SE 9	37N	6E	1,463	624	- -	- -	Tr	160	133	1,110	27.13	- - -	- - -	- - -	4.51	4.43	18.19	16.62	- - -	83.38	- - -	100.00	- - -
46	Bears Den (Glacial drift)	1	SW 12	36N	5E	2,287	837	50	Tr	609	12	- -	1,585	36.49	2.50	- - -	12.68	0.34	- - -	25.97	33.40	- - -	60.18	6.42	2.64	97.36
47	Grassy Butte (Virgelle)	- -	SE 29	35N	3E	950	233	44	49	355	9	- -	530	10.10	2.20	4.03	7.40	0.25	- - -	8.68	46.84	- - -	15.00	38.16	3.25	96.75
48	Utonia (Upper Eagle	1	SE 11	33N	5E	4,131	1,448	- -	- -	2,041	175	59	830	63.00	- - -	- - -	42.49	4.94	1.97	13.60	75.28	- - -	24.72	- - -	10.41	89.59
49	Boxelder	2	SW 14	32N	17E	9,951	3,032	- -	- -	523	4,567	187	1,530	171.00	- - -	- - -	10.89	128.80	6.23	25.08	81.70	- - -	18.30	- - -	92.19	7.81
50	Bowes		SE 28	32N	20E	1,879	786	- -	- -	- -	407	Tr	1,390	34.27	- - -	- - -	- - -	11.48	- - -	22.79	33.50	- - -	66.50	- - -	100.00	- - -
51	Rattlesnake Butte	1	SE 22	13N	28E	1,984	773	- -	- -	413	177	109	1,000	33.61	- - -	- - -	8.60	4.99	3.63	16.39	40.44	- - -	59.56	- - -	36.73	63.27
52	Rattlesnake Butte	1	SE 22	13N	28E	1,653	688	- -	- -	95	213	168	995	29.90	- - -	- - -	1.98	6.01	5.60	16.31	26.72	- - -	73.28	- - -	75.22	24.78
53	Broadview dome		NW 18	3N	23E	3,127	1,340	- -	- -	- -	265	Tr	3,115	58.25	- - -	- - -	- - -	7.19	- - -	51.06	12.34	- - -	87.66	- - -	100.00	- - -
	CLAGGETT SHALE WATERS:																									
54	Signal Butte	1	NW 20	37N	15E	9,249	3,516	61	37	35	5,534	- -	135	152.96	3.04	3.04	0.73	156.10	- - -	2.21	96.16	2.44	- - -	1.40	99.53	0.47
	JUDITH RIVER FORMATION WATERS:																									
55	Boxelder	1	SE 9	32N	17E	6,967	2,717	30	- -	Tr	4,005	- -	265	118.19	1.50	- - -	- - -	115.51	- - -	4.18	96.50	- - -	2.24	1.26	100.00	- - -
56	Boxelder	1	NE 11	32N	17E	9,003	3,466	45	20	34	5,304	12	245	150.79	2.30	1.65	0.71	149.51	0.40	4.02	97.14	- - -	0.30	2.56	99.53	0.47
	JUDITH RIVER FORMATION WATERS:										EASTERN FIELDS															
57	Wolf Point	1	15	27N	47E	4,841	1,919	18	- -	- -	2,422	Tr	980	83.47	0.90	- - -	- - -	68.31	- - -	16.06	80.96	- - -	17.98	1.06	100.00	- - -
58	Cedar Creek anticline	1	NE 20	14N	55E	14,585	5,542	123	44	- -	8,785	- -	185	241.07	6.14	3.62	- - -	247.80	- - -	3.03	96.12	2.68	- - -	1.20	100.00	- - -
59	Cedar Creek anticline	13	SW 1	13N	55E	17,847	6,790	153	47	- -	10,736	- -	245	295.35	7.64	3.87	- - -	302.84	- - -	4.02	96.24	2.46	- - -	1.30	100.00	- - -
60	Cedar Creek anticline	1-9	SE 35	14N	57E	9,187	3,396	94	37	513	4,978	- -	140	147.90	4.69	3.04	12.76	140.42	- - -	2.29	94.02	3.50	- - -	1.48	91.68	8.32
61	Cedar Creek anticline	87	SE 9	11N	57E	12,005	4,586	119	36	- -	7,176	- -	260	197.74	5.94	2.96	- - -	202.38	- - -	4.26	95.70	2.24	- - -	2.06	100.00	- - -
62	Cedar Creek anticline	88	SW 10	11N	57E	12,224	4,636	135	Tr	342	6,968	- -	220	201.65	6.74	- - -	7.12	196.52	- - -	4.75	96.76	0.96	- - -	2.28	96.50	3.50
63	Cedar Creek anticline	3	SW 10	11N	57E	10,406	3,238	120	30	- -	7,000	- -	220	140.89	5.99	2.47	- - -	146.74	- - -	3.61	94.20	3.40	- - -	2.40	100.00	- - -
64	Cedar Creek anticline	90	NW 23	11N	57E	11,871	4,547	117	Tr	- -	7,072	- -	265	197.79	5.84	- - -	- - -	199.45	- - -	4.18	97.14	0.80	- - -	2.06	100.00	- - -
65	Cedar Creek anticline	60	SE 26	11N	57E	11,143	4,244	127	- -	35	6,700	- -	75	184.62	6.34	- - -	0.73	189.00	- - -	1.23	96.68	2.68	- - -	0.64	99.62	0.38
66	Cedar Creek anticline	52	NE 1	10N	58E	10,281	3,974	74	Tr	- -	6,084	Tr	304	172.88	3.69	- - -	- - -	171.59	- - -	4.98	97.18	- - -	0.72	2.10	100.00	- - -
67	Cedar Creek anticline	4	SE 16	10N	58E	12,007	4,468	182	34	126	7,072	- -	255	194.37	9.08	2.80	2.62	190.45	- - -	4.18	94.24	3.74	- - -	2.02	98.70	1.30
68	Cedar Creek anticline	2	NW 22	10N	58E	11,505	4,415	105	- -	27	6,854	30	130	192.04	5.24	- - -	0.56	193.59	1.00	2.13	97.34	1.08	- - -	1.58	99.70	0.30
69	Cedar Creek anticline	4	SE 32	10N	58E	8,547	3,268	69	Tr	82	4,975	- -	270	143.02	3.44	- - -	1.71	140.33	- - -	4.42	96.98	- - -	0.88	2.34	98.80	1.20
70	Cedar Creek anticline	1	NW 6	9N	59E	10,830	4,068	119	44	34	6,442	- -	260	176.96	5.94	3.62	0.71	181.71	- - -	4.10	94.88	2.92	- - -	2.20	99.61	0.39
71	Cedar Creek anticline	2	NE 18	9N	59E	12,135	4,567	124	45	- -	7,271	Tr	260	198.67	6.99	3.70	- - -	206.10	- - -	4.26	94.90	3.06	- - -	2.04	100.00	- - -
72	Cedar Creek anticline	1	NW 28	9N	59E	9,943	3,754	87	33	155	5,710	- -	395	153.73	4.34	2.71	3.23	161.07	- - -	6.48	95.88	0.32	- - -	3.80	98.04	1.96
73	Cedar Creek anticline	2	SW 28	8N	60E	8,409	3,233	101	Tr	58	5,026	- -	155	140.64	5.04	- - -	1.21	141.77	- - -	2.70	96.54	1.60	- - -	1.86	99.16	0.84
74	Cedar Creek anticline	1	SW 34	132N	107E	16,301	5,980	276	84	46	9,858	- -	115	260.24	13.77	6.91	0.96	278.07	- - -	1.89	92.84	6.68	- - -	0.68	99.66	0.34

The Big Snowy-Judith Mountain anticlinorium, in the central part of the state, contains the Cat Creek and several other smaller and unimportant oil or gas fields. The only important producing area in eastern Montana is the Cedar Creek (Baker-Glendive) anticline which trends about 100 miles south-southeast from Glendive, Montana, into the southwest corner of North Dakota.

In Montana oil and gas in commercial quantities have been found in strata ranging in age from Lower Mississippian to Upper Cretaceous, the most productive oil zones being in the Madison limestone, the Kootenai formation, and the Cloverly formation (Fig. 2). The most productive gas zones are in the Kootenai formation, the Colorado shale, and the Eagle sandstone and Judith River formation of the Montana group. Showings of oil or gas have been found in these and other zones in many scattered areas throughout the plains.

Arrangement of Analyses

Because there are not many well defined geographical and structural basins in Montana, such as are found in Wyoming, the oil and gas fields of Montana are grouped herein in areas, or fields, that are rather poorly defined geographical and geological units. The areas, with their important oil or gas fields, are: (1) Sweetgrass arch fields: Kevin-Sunburst, Cut Bank, Pondera, Border-Red Coulee, and Devon gas area; (2) Sweetgrass Hills fields: Whitlash, Bears Den, Flat Coulee, Berthelote, Pinhorn, and Grassy Butte; (3) north-central fields (the area from the vicinity of Havre to Bowdoin dome): Bowdoin, Bowes, Boxelder; (4) central and southern fields: Cat Creek, Devils Basin, Dry Creek, Soap Creek, and Big Lake; and (5) eastern fields, in which the Cedar Creek anticline is the only producing district. Fields and individual wells in the fields are arranged from north to south, and west to east in the tables.

Montana Group Waters

Excluding shallow wells and springs in the Fox Hills sandstone and Lance formation, of latest Upper Cretaceous age, the first important oil-field waters encountered are those in the Montana group of Upper Cretaceous age. This group includes, in descending order, the Horsethief sandstone, Bearpaw shale, Two Medicine formation, and Eagle sandstone in northwestern Montana; and the Bearpaw shale, Judith River formation, Claggett shale, and Eagle sandstone in southern and central Montana. The Two Medicine formation in northwestern Montana is correlative with the Judith River, Claggett, and part of the Eagle sandstone of central and southern Montana.

The Montana group is 2,200 to 2,500 feet thick, and is underlain by the Colorado shale, also of Upper Cretaceous age. Showings of oil have been found in the Judith River formation, but no commercial wells have been developed. Commercial quantities of gas are produced from Judith River and Eagle sandstones in the south-central and eastern part of the state, but elsewhere the Montana group is water-bearing.

SWEETGRASS ARCH FIELDS[6]

WATERS OF TWO MEDICINE FORMATION AND VIRGELLE MEMBER OF EAGLE SANDSTONE

The Two Medicine formation comprises 1,650 to 1,950 feet of gray to greenish gray shale, mudstone, and siltstone, with massive, light gray sandstone in its lower 250 feet, and thin coal beds near the base. The formation crops out in 2,000 square miles in this area.

Milk River anticline.—The asymmetrical Milk River anticline in T. 36 N., R. 12 W., is a large and persistent feature near the north end of the Disturbed Belt in Montana, and the most westerly structure yet drilled on the plains. Overthrust faulting is characteristic of the Disturbed Belt, and tests may stop in beds stratigraphically higher than those in which they were started, or in nearly vertical strata on the limbs of a closely compressed fold.[7] The last test made on this structure, the Fulton Blackfeet Oil Company's Gerard No. 1, began in the Two Medicine formation, which was penetrated at a depth of 1,150 feet. A normal section continued to 2,170 feet, where the bit passed from Colorado shale back to Two Medicine formation at an overthrust fault. Drilling continued to a total depth of 4,257 feet, and all of the section below 2,170 feet is probably Two Medicine. Since this footage exceeds the normal thickness of the section in this neighborhood, it is probable that other overthrust faults were drilled.

Showings of oil and gas were not found. The Two Medicine formation consists of greenish gray shale and sand, siltstone, and minor amounts of grayish brown concretionary limestone. A sand found at a depth of 60–65 feet yielded a large volume of water, which was cased off before being sampled. A hard sand, found at a depth of 235–245 feet, yielded a little water whose chemical character is shown in analysis 1, Table I. This water is of the primary alkaline type, and wholly unlike Two Medicine water in the Cut Bank district at the east in which the sulphate radicle predominates. It is comparatively dilute, potable, and resembles meteoric water from an igneous source, but it seems impossible to reconcile these characteristics with local geologic conditions.

Cut Bank district.—The Cut Bank field, approximately 33 miles long and 4 miles wide, trends north and south through Ts. 37–32 N., and Rs. 7–5 W., and produces gas and oil from sands in the Kootenai formation of Lower Cretaceous age. The Two Medicine formation, which crops out widely in the field, rests directly on the Virgelle sandstone member of the Eagle sandstone. At the north end of the district, from Headlight Butte northeast, a thin westward-lensing wedge of Claggett shale is recognizable. Here Two Medicine rests on Claggett,

[6] A rather complete and up-to-date discussion of the stratigraphy of the Sweetgrass arch is given by Charles E. Erdmann and John R. Schwabrow, "Border-Red Coulee Oil Field, Toole County, Montana, and Alberta, Canada," *Stratigraphic Type Oil Fields* (Amer. Assoc. Petrol. Geol., 1941), pp. 267–326.

[7] Rocky Mountain Association of Petroleum Geologists, "Possible Future Oil Provinces in Rocky Mountain Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 8 (August, 1941), pp. 1471–74.

which in turn rests on the upper part of the Eagle sandstone. The Virgelle sandstone consists of about 300 feet of brownish gray and gray sandstone, underlain by a transition zone into the Colorado shale of about 135 feet of soft, gray to brown, silty, fine-grained sandy shale, with layers of calcareous concretions.

Cut Bank Creek flows southeastward across the southwest corner of the Cut Bank field to its confluence with Two Medicine Creek to form the Marias River. These creeks flow on perched water tables, cutting across exposures of Two Medicine formation and Virgelle sandstone, but apparently contribute no water to them, as deep wells drilled within 500 yards of Cut Bank Creek are dry down into the Kootenai formation. The source of the Two Medicine and Virgelle water in the Cut Bank field is doubtless in the hundreds of square miles of outcrops of these formations in the area.

Primary salinity and alkalinity dominate Two Medicine waters in the Cut Bank field, with secondary characteristics sometimes present in minor proportions. The waters range in concentration from 8,000 parts per million to 800 parts per million, with an average of 3,000 parts per million. Their composition is somewhat erratic, probably owing to surface water intrusion from the outcrops in and near the field, but more probably because of local areas of low permeability. However, they can always be differentiated from lower waters (except the Virgelle) by the preponderance of sulphate over chloride. No other water in the Cut Bank field below the Montana group contains more sulphate than chloride.

The Virgelle water in the Cut Bank field is, as a rule, much more dilute than that from the overlying Two Medicine, but has the same composition, being essentially a solution of sodium sulphate and sodium bicarbonate. Apparently better sand conditions cause it to be much more uniform in composition and concentration than Two Medicine water.

For practical field purposes it is not necessary to differentiate between Two Medicine, mixed Two Medicine and Virgelle, and Virgelle waters in the Cut Bank field. Both Two Medicine and Virgelle waters are shut off by a single string of casing, and all intrusive water from the Montana group can be identified by the 3 to 1, or greater, ratio of sulphate to chloride.

Border-Red Coulee nose.—In the Border-Red Coulee field, T. 37 N., R. 4 W., the Virgelle member of the Eagle sandstone consists of about 300 feet of gray to buff, coarse-grained, cross-bedded, massive sandstone, grading to slabby gray sandstone near its base, the top of the Virgelle lying about 50 feet below the surface.[8] The sand yielded about 125 barrels of water a day per well, which was used in oil-field operations. The water is essentially of the same composition as that in the Virgelle member of the Eagle sandstone at Cut Bank. The preponderance of sulphate over chloride distinguishes this water from any other water in the Border-Red Coulee field. Waters from zones in the Colorado shale, and from the Cosmos-Vanalta sands of the Kootenai in the Border-Red Coulee

[8] C. E. Erdman and J. R. Schwabrow, *op. cit.*, pp. 279–280.

field have only minor quantities of sulphate, chloride dominating the negative radicles of the system.

In Sec. 28, T. 36 N., R. 4 W., about 10 miles south of the Border-Red Coulee field, an early wildcat test drilled the top of the Virgelle member of the Eagle sandstone at a depth of about 105 feet. The main body of the sandstone, excluding the transitional zone, is about 247 feet thick. Sample 42 was obtained at a depth of 215 feet, or 110 feet below the top, and is similar to waters from the Virgelle member of the Eagle sandstone in the Cut Bank and Border-Red Coulee fields.

SWEETGRASS HILLS AND NORTH-CENTRAL FIELDS

The sands of the Montana group are relatively important from an oil and gas standpoint in the Sweetgrass Hills and north-central areas east of the Sweetgrass Hills and north of the Bearpaw Mountains. Although the Judith River formation is not known to contain gas or oil in this area, the Virgelle member of the Eagle sandstone is the important gas zone in the Bowes and Boxelder fields of the north-central area. In the Bowdoin field at the east, however, typical Eagle sandstone is absent and the horizon can be identified only by measuring from other formation boundaries.

Waters from the Montana group sandstones in this area are difficult to correlate. Infiltration of meteoric waters into the sands has diluted and destroyed the recognizable connate characteristics of most of the samples. The glacial drift, which covers the Montana group formation in this area to a thickness of as much as 300 feet, contains water in many fields that has been confused with Eagle water. In this part of Montana the Eagle sandstone consists of two, or possibly three, parts: the upper part, which is of continental origin and contains coal; the middle part, which is the massive Virgelle sandstone member; and the basal transitional zone (really Telegraph Creek equivalent). All of the gas production and most of the water comes from the Virgelle member, but, at least in two places, the upper part of the Eagle sandstone formation, which is mostly shale, yields water.

Analysis 54, Table I, is of water from a well drilled on the Signal Butte structure, T. 37 N., R. 15 E. The water came from a sandy shale at the base of the Claggett shale at a depth of 905–920 feet. The surface formation is Judith River, and the subjacent Claggett consisted of 550 feet of dark clay shale and sandy shale. The water encountered in the Claggett rose to within 60 feet of the surface, being saline and of a comparatively high degree of concentration. Sulphate was negligible, and secondary characteristics occupied less than 4 per cent of the chemical system. The interesting thing about this water is its resemblance to Virgelle waters in the Boxelder anticline and to "Judith River" waters in the Cedar Creek anticline. It appears to be a modified connate water, and it is probably the only sample of connate Claggett water found thus far. Its high concentration suggests semi-stagnant conditions within the formation.

Waters from the Judith River formation have been sampled in the north-central area only in the Boxelder anticline, T. 32 N., R. 17 E., where the formation consists of gray shale, thin sandstones, and fresh-water marls. The top of a basal water-bearing sandstone about 35 feet thick was logged at a depth of 300 feet in well No. 1, Sec. 11. The Virgelle member of the Eagle sandstone at Boxelder contains gas, and some water is found in it at depths averaging 580 to 600 feet. Analysis 49 is representative of this Eagle water.

Both Judith River and Virgelle waters at Boxelder are moderately concentrated saline waters with negligible amounts of sulphate; both have concentrations of 7,000 to 9,000 parts per million; both have minor quantities of calcium and magnesium, although these alkaline earths have been precipitated from the Virgelle water. They differ in only one respect—alkalinity. The Judith River water has a low bicarbonate content, and the Virgelle water a high bicarbonate content, which is sufficient to differentiate them.

The Judith River, Claggett, and Eagle (Virgelle) sandstones were laid down in the same body of water—the Upper Cretaceous epicontinental sea. For this reason, excluding modification by circulating ground waters, a definite resemblance between the three waters would be expected, and this resemblance can be found in the above described waters. The presence of more than 500 parts per million sulphate in the sample of Virgelle water from Boxelder indicates either drilling-water contamination or modification by circulating ground water. The Claggett and Judith River waters contain negligible quantities of the sulphate ion and are almost identical in chemical composition. "Judith River" waters from Cedar Creek anticline, although more concentrated than the preceding examples, show a striking similarity in chemical composition.

These samples are too few to warrant any definite statements as to character of water in formations laid down in the same sea, but would seem to indicate a uniform composition of this sea throughout a long period of geologic time, and, perhaps of more importance to the student of water analyses, that the different geographic and geologic environments evidently have had little effect upon the composition of the water.

Analysis 43 is from the Virgelle member of the Eagle sandstone at Berthelote district in T. 36 N., R. 1 E. The upper part of the Eagle sandstone is the surface formation and the top of the Colorado shale is reached at a depth of about 300 feet. The water, coming as it does from relatively shallow depths, is probably ground water.

Analysis 47 is from a spring in the alluvium at the base of a Virgelle sandstone cliff at Grassy Butte in T. 35 N., R. 3 E. The spring was flowing approximately 17 barrels an hour, and the water is almost identical in composition with Virgelle water at Cut Bank, the high ratio of sulphate to chloride denoting surface water.

The Pinhorn district occupies T. 37 N., R. 6 E., and consists of a series of small noses which digitate and plunge eastward from Flat Coulee dome as fingers from a hand. The top of the Eagle sandstone was logged at a depth of

about 735 feet, and the top of the Virgelle sandstone member at a depth of about 890 feet. The base of the Virgelle sandstone member was logged at a depth of 1,096 feet, and the top of the Colorado shale at a depth of 1,157 feet. Sample 45 was taken between the depths of 855 and 869 feet; hence it is from the upper part of the Eagle sandstone, which is lithologically much like the Judith River formation.

Analysis 48 is also a sample from the upper part of the Eagle sandstone. Utopia, T. 33 N., R. 6 E., is a nose plunging eastward from the east side of Kevin-Sunburst dome, and might better be included in the Sweetgrass arch fields. In the well from which sample 48 was taken the top of the Eagle sandstone was drilled at a depth of about 500 feet, and the top of the Virgelle member at a depth of 655 feet. Water was found at a depth of 635 feet. This water with its high sulphate content is radically different from equivalent water at Pinhorn, and its higher concentration would indicate a restricted water movement in the sand.

Included in Table I under Eagle waters are samples 44 and 46, which are from the glacial drift. Sample 44 is from Whitlash dome, T. 37 N., R. 4 E., the largest producing field in the Sweetgrass Hills area. Gas is produced from sands in the Blackleaf member of the Colorado shale, and from sands in the lower part of the Kootenai. Two wells produce oil from the Colorado shale in the southeast corner of the field. Land surface is occupied by glacial drift which has a thickness of as much as 300 feet. The Colorado shale is exposed over the central part of the dome and the Eagle sandstone occupies the flanks. Sample 44 came from a gravel bed at a depth of 140–142 feet; the glacial drift was 280 feet thick in this well.

Sample 46 was taken at a depth of only 50 feet on the Bears Den structure in T. 36 N., Rs. 5–6 E. Here the surface formation is Colorado shale, which underlies about 50 feet of glacial drift. The water is evidently from the base of the glacial drift, and correlates favorably with equivalent water from Whitlash dome.

Bowes dome, T. 31–32 N., R. 19 E., produces gas from the Virgelle member of the Eagle sandstone. This member is about 205 feet thick and is encountered between depths of 600 and 1,000 feet atop the structure. There is no water with the gas in the producing parts of the field. The well from which sample 50 was obtained is about 6 miles east of the field and logged the top of the Virgelle member of the Eagle sandstone at a depth of 1,150 feet, where it stopped drilling. The well was completed as a small gas well, but also made considerable water.

CENTRAL FIELDS

The only Montana group waters sampled in the central fields are Eagle (Virgelle?) waters in Rattlesnake Butte and Broadview dome. At Rattlesnake Butte, T. 13 N., R. 28 E., the Claggett shale crops out. In the well represented by samples 51 and 52, the top of the Eagle (upper?)—a gray, fine sand—was

logged at a depth of 489 feet, and at 499 feet shale was logged. Sample 51 was taken, and the 12½-inch casing was cemented at a depth of 520 feet. Between 540 and 600 feet more sand was logged, containing water, which is represented by sample 52. The total thickness of the Eagle sandstone is 111 feet, that is, from 489 to 600 feet. The upper and lower waters are very similar although the lower water is less saline.

The sample from Broadview dome, T. 3 N., R. 23 E., came from a shallow water well used for drilling purposes. The Eagle (Virgelle?) sandstone crops out on the dome, and source water for the sand is probably surface water that has flowed across an area of Claggett shale.

EASTERN FIELDS

In the eastern area the terms "Judith River" and "Eagle" are strictly local usage as the formations can not be positively correlated with typical Judith River formation and Eagle sandstone to the northwest because of lack of exposures. The formations yield commercial amounts of gas in the Cedar Creek (Baker-Glendive) anticline, the "Judith River" being the principal producer.

A well drilled at Wolf Point, T. 27 N., R. 47 E., Roosevelt County, found 1,000 barrels of water and 20,000 cubic feet of gas per day in the basal sand of the "Judith River" at a depth of 1,007 feet. This water is more dilute and more alkaline than "Judith River" water at Cedar Creek.

Cedar Creek anticline.—The Cedar Creek anticline is the only producing district in eastern Montana, and is an asymmetric fold with local "highs," about 100 miles long, extending into the southwest corner of North Dakota. The "Judith River" sand is the most important gas zone, although some gas is taken from the "Eagle" sandstone, about 650 feet below the "Judith River." Both the "Judith River" and "Eagle" are thin, lenticular, and shaly.

In Ts. 13 and 14 N. (Gas City dome) the "Judith River" sand is about 42 feet thick, and lies about 750 to 800 feet below the surface. In Ts. 11 and 12 N. (Ash Creek dome) the "Judith River" sand averages 60 feet in thickness, and is divided into three sections by thin shale breaks. The top of the sand lies 800 to 850 feet below the surface. In Ts. 9 and 10 N. (Cabin Creek dome), the "Judith River" sand thickens to about 80 feet, with two thin shale breaks in some wells, and the top of the sand is logged at depths of 750 to 900 feet, depending on structural position. South of T. 6 N. the "Judith River" sand lies 900 to 1,000 feet below the surface and is broken sand and shale. The main gas production is south of T. 11 N., and north of T. 7 N.

There is not much water in any of the wells at Cedar Creek, except in edge wells which produce a few barrels a day, and there is much less water in the southern part of the anticline than in the central and northern parts. The analyses in Table I are largely from edge and "off-structure" wells. The high concentration of the water may be partly due to the evaporative effect of expanding gas, and the presence of sulphate in many of the samples indicates surface water contamination.

SUMMARY

Montana group waters are usually dilute to moderately dilute solutions of sodium salts, sodium sulphate predominating in the chemical system in those areas where surface water has access to the sands through outcrops on or near the structures. Secondary characteristics are ordinarily present to some extent, but seldom in excess of the primary characteristics. Where secondary characteristics are present, it is not exceptional to find the ratio of magnesium to calcium greater than unity.

In most of those deeper Montana group sands, where surface water has not had easy access, a moderately concentrated to concentrated water, in which sodium chloride is the dominant salt, is found. These waters are ordinarily associated with gas and also have a small percentage of secondary characteristics.

Colorado Group Waters

In Montana the Colorado group, or shale, of Upper Cretaceous age, includes, besides dark fissile shale, the sandy Frontier formation of southern and eastern Montana, the First Cat Creek sand in central Montana, the upper and middle parts of the Blackleaf sandy member in the Sweetgrass arch and vicinity, and the Martin, Bowdoin, and Phillips gas zones in the Bowdoin field. The group is underlain by the Kootenai formation, of Lower Cretaceous age, in northern and central Montana, and by the Cloverly formation of Lower Cretaceous age in southern and eastern Montana. Locally the group is as much as 2,000 feet thick. Sandy zones in the Colorado yield oil or gas at several localities in the plains.

SWEETGRASS ARCH FIELDS

Border-Red Coulee nose.—The Colorado shale in the Border-Red Coulee field averages 1,710 feet in thickness, with a light gray, medium-coarse sandstone member 10 to 20 feet thick near its base. Practically all wells found only water in this sandstone, the top of which lies about 1,900 feet below the surface. This sand was called the "Colorado water sand" or the "1,900-foot sand" when the field was under development.

The basal Colorado water in the Border-Red Coulee field is a concentrated, saline water similar to basal Colorado waters elsewhere in the Sweetgrass arch area. Its average concentration of about 16,000 parts per million, and a chloride content of about 9,000 parts per million, differentiates it from other waters in the field, no other water containing half as much chloride or soluble salts.

Cut Bank district.—In the Cut Bank field approximately 1,710 feet of Colorado shale lies disconformably on the Kootenai, the top of the Colorado being found at an average depth of 500 feet below the surface. The top of the Colorado consists of black, fissile marine shale. A basal member—the Blackleaf sandy member—occupies the lower 800 feet of the Colorado and consists of sandy shale, sandstone, conglomeratic sandstone, carbonaceous shale, and bentonite. The "red speck zone," lying about 305 feet below the top of the Blackleaf sandy

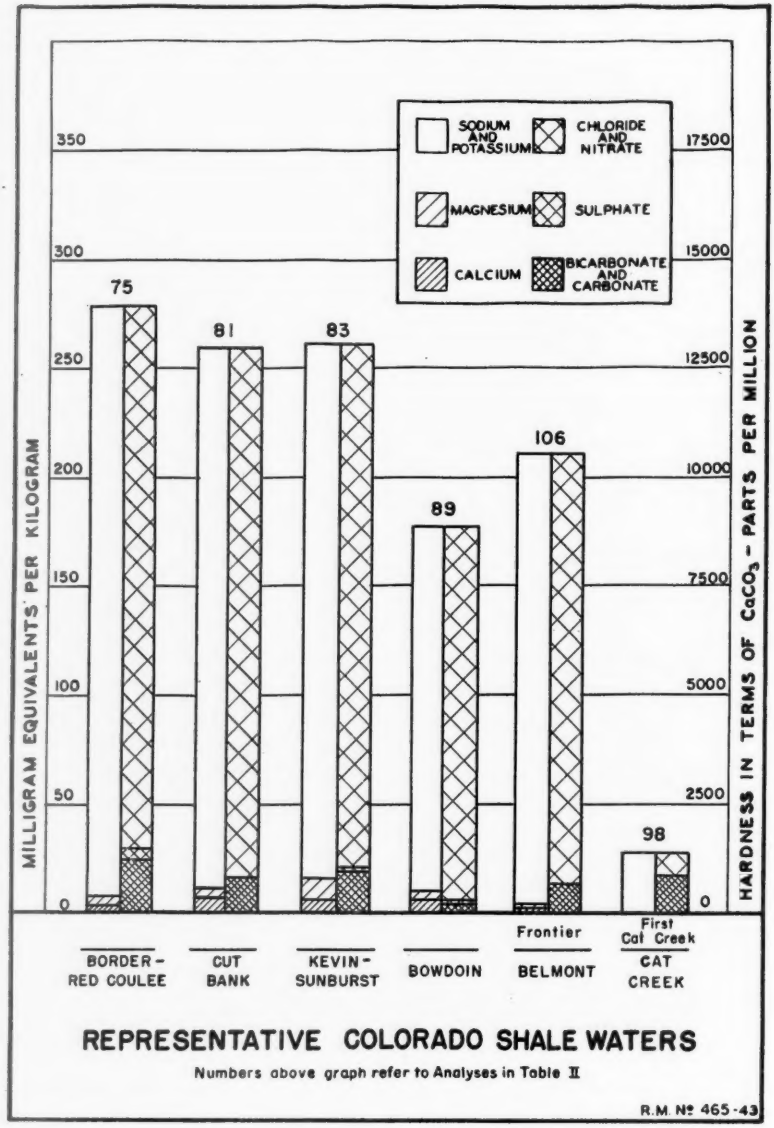

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
350
300
250
200
150
100
50
0
17500
15000
12500
10000
7500
5000
2500
0
75
81
83
89
106
98
BORDER - RED COULEE
CUT BANK
KEVIN - SUNBURST
BOWDOIN
Frontier BELMONT
First Cat Creek CAT CREEK
REPRESENTATIVE COLORADO SHALE WATERS
Numbers above graph refer to Analyses in Table II
R.M. Nº 465-43

FIG. 4

TABLE II

COLORADO SHALE WATERS

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
						SWEETGRASS ARCH FIELDS																				
75	Border-Red Coulee	2	SW 2	37N	4W	15,969	6,203	39	43	188	8,800	- -	1,415	269.84	1.95	3.58	3.91	246.23	- - -	23.19	91.58	- - -	6.42	2.00	98.45	1.55
76	Border-Red Coulee	1	NW 13	37N	4W	16,208	6,272	81	42	30	9,050	- -	1,490	272.83	4.04	3.45	0.62	255.28	- - -	24.42	91.28	- - -	6.04	2.68	99.74	0.26
77	Cut Bank	1	NW 27	36N	5W	8,189	3,114	41	Tr	841	3,856	- -	585	135.45	2.05	- - -	17.51	108.77	- - -	11.22	91.84	- - -	6.68	1.48	86.14	13.86
78	Cut Bank	1	SE 16	35N	5W	14,339	5,510	126	30	Tr	7,938	- -	1,495	239.67	6.29	2.47	- - -	223.92	- - -	24.51	90.14	- - -	6.34	3.52	100.00	- - -
79	Cut Bank	1	SW 25	35N	6W	17,380	6,841	200	Tr	33	10,152	- -	720	288.88	9.98	- - -	0.69	286.37	- - -	11.80	96.06	- - -	0.60	3.34	99.75	0.25
80	Cut Bank	1	SE 10	32N	5W	13,392	5,119	146	- -	81	7,795	59	390	222.66	7.29	- - -	1.69	219.89	1.97	6.40	96.36	- - -	0.48	3.16	99.23	0.77
81	Cut Bank	1	NW 29	32N	4W	14,906	5,706	126	35	- - -	8,572	- -	950	248.10	6.29	2.88	- - -	241.79	- - -	15.57	93.06	- - -	2.48	3.56	100.00	- - -
82	Cut Bank	1	SW 1	31N	5W	14,452	5,213	278	133	66	8,172	- -	1,200	226.75	13.87	10.93	1.37	230.51	- - -	19.67	90.14	2.04	- - -	7.82	99.42	0.58
83	Kevin-Sunburst	1	NE 2	33N	4W	14,036	5,635	87	115	72	8,476	- -	1,120	245.14	4.34	9.46	1.50	239.08	- - -	18.36	92.90	- - -	1.76	5.34	99.38	0.62
84	Kevin-Sunburst	1	SW 19	32N	1W &	10,318	4,046	16	7	- -	6,050	- -	405	175.92	0.80	0.58	- - -	170.66	- - -	6.64	96.26	- - -	2.94	0.80	100.00	- - -
85	Devon	1	NE 29	33N	2E	7,785	2,775	295	Tr	- -	4,248	- -	950	120.65	14.72	- - -	- - -	119.80	- - -	15.57	88.50	- - -	0.62	10.88	100.00	- - -
						SWEETGRASS HILLS FIELDS																				
86	Whitlash	1	NE 26	37N	4E	7,112	2,809	19	- -	- -	3,834	- -	915	122.20	0.95	- - -	- - -	108.15	- - -	15.00	87.82	- - -	11.40	0.78	100.00	- - -
87	Pinhorn	1	SE 9	37N	6E	1,776	712	- -	- -	245	275	185	730	30.98	- - -	- - -	5.10	7.76	6.16	11.96	41.50	- - -	58.50	- - -	60.34	39.66
88	Flat Coulee	1	SW 10	37N	5E	7,469	3,124	Tr	- -	Tr	1,750	144	4,890	135.84	- - -	- - -	- - -	48.36	4.80	81.68	36.30	- - -	63.70	- - -	100.00	- - -
						NORTH CENTRAL FIELDS																				
89	Bowdoin	603	NW 32	33N	33E	10,208	3,840	89	54	47	6,053	- -	255	166.99	4.44	4.44	0.98	170.71	- - -	4.18	94.96	2.66	- - -	2.38	99.43	0.57
90	Bowdoin	4	SW 36	32N	32E	7,108	2,676	54	39	142	4,000	- -	400	116.43	2.70	3.21	2.95	112.83	- - -	6.56	94.60	- - -	0.40	5.00	97.46	2.54
91	Bowdoin	1	SW 2	31N	34E	8,681	3,263	50	64	- -	5,143	- -	310	141.95	2.94	5.26	- - -	145.07	- - -	5.08	94.54	2.08	- - -	3.38	100.00	- - -
92	Bowdoin	1	SW 8	31N	34E	6,107	2,330	39	29	- -	3,465	- -	495	101.52	1.95	2.38	- - -	97.73	- - -	8.12	92.32	- - -	3.58	4.10	100.00	- - -
	FIRST CAT CREEK SAND WATERS:					CENTRAL FIELDS																				
93	Cat Creek	1	SW 10	15N	29E	1,672	670	16	6	18	376	67	1,054	29.19	0.80	0.49	0.37	10.60	2.22	17.29	36.00	- - -	59.76	4.24	96.67	3.33
94	Cat Creek	2	SW 11	15N	29E	1,137	483	- -	- -	- -	150	- -	975	21.03	- - -	- - -	- - -	4.23	- - -	16.80	20.08	- - -	79.92	- - -	100.00	- - -
95	Cat Creek	1	NW 13	15N	29E	1,583	696	Tr	- -	- -	460	- -	950	28.55	- - -	- - -	- - -	12.98	- - -	15.57	45.40	- - -	54.60	- - -	100.00	- - -
96	Cat Creek	2	NW 13	15N	29E	1,504	624	Tr	- -	Tr	430	- -	915	27.13	- - -	- - -	- - -	12.13	- - -	15.00	44.20	- - -	55.20	- - -	100.00	- - -
97	Cat Creek	3	NW 13	15N	29E	1,399	584	Tr	- -	- -	340	- -	915	25.41	- - -	- - -	- - -	9.59	- - -	15.82	37.64	- - -	62.36	- - -	100.00	- - -
98	Cat Creek	4	NW 13	15N	29E	1,484	617	Tr	- -	- -	400	Tr	950	26.85	- - -	- - -	- - -	11.28	- - -	15.57	42.00	- - -	58.00	- - -	100.00	- - -
99	Cat Creek	8	NW 13	15N	29E	1,394	591	---	- -	- -	400	Tr	880	25.71	- - -	- - -	- - -	11.28	- - -	14.42	43.84	- - -	56.16	- - -	100.00	- - -
100	Cat Creek	2	NW 14	15N	29E	2,105	860	- -	- -	- -	800	- -	905	37.40	- - -	- - -	- - -	22.57	- - -	14.83	60.20	- - -	39.80	- - -	100.00	- - -
101	Cat Creek	5	NE 14	15N	29E	1,688	713	- -	- -	- -	326	- -	1,318	31.02	- - -	- - -	- - -	9.40	- - -	21.62	30.30	- - -	69.70	- - -	100.00	- - -
102	Cat Creek	6	NE 14	15N	29E	1,861	765	- -	- -	Tr	620	- -	965	33.31	- - -	- - -	- - -	17.49	- - -	15.82	52.40	- - -	47.60	- - -	100.00	- - -
103	Cat Creek	1	SW 21	15N	30E	2,073	847	- -	- -	13	752	Tr	938	36.86	- - -	- - -	0.27	21.31	- - -	15.38	68.38	- - -	31.62	- - -	98.73	1.27
104	Cat Creek	2	NW 26	15N	30E	2,262	936	- -	- -	17	766	Tr	1,080	40.06	- - -	- - -	0.35	21.60	- - -	18.11	54.84	- - -	45.16	- - -	98.36	1.64
105	Devils Basin	1	SE 9	10N	25E	3,042	1,235	- -	- -	45	1,162	Tr	1,220	53.72	- - -	- - -	0.94	32.78	- - -	20.00	62.76	- - -	37.24	- - -	97.23	2.77
	FRONTIER FORMATION WATERS:					SOUTHERN FIELDS																				
106	Belmont	1	SE 28	6N	22E	12,154	4,735	43	17	- -	6,978	Tr	775	205.99	2.15	1.40	- - -	196.84	- - -	12.70	93.94	- - -	4.36	1.70	100.00	- - -
107	Lake Basin	4	24	4N	21E	32,755	12,566	217	83	- -	19,240	- -	1,320	546.51	10.83	6.83	- - -	542.63	- - -	21.64	96.16	- - -	0.70	3.14	100.00	- - -
108	Laurel	1	SE 30	2S	24E	1,709	733	- -	- -	- -	123	91	1,550	31.90	- - -	- - -	- - -	3.47	3.03	25.40	10.88	- - -	89.12	- - -	100.00	- - -

member, is an important marker bed and consists of gray to black bentonitic shale, 0 to 25 feet thick, containing small crystals of an orange-red zeolite. The Blackleaf member contains water and a little gas, but no commercial oil or gas wells have been developed in it in the Cut Bank field.

The water from the Colorado shale in the Cut Bank field has about the same concentration and characteristics as Colorado water in the Border-Red Coulee and Kevin-Sunburst fields. Salinity occupies 90 to 96 per cent of the chemical system, and the salinity is caused almost entirely by chloride, the amount of sulphate present being negligible. The high chloride content differentiates this water from that in the overlying Montana group. It is, however, more difficult to differentiate Kootenai water from Colorado water, though the higher alkalinity of the former helps to identify them. In many instances, however, only a careful comparison with known analyses from near-by wells differentiates them. Water from the Madison limestone can be recognized easily by its lower concentration —2,000 to 5,000 parts per million—and by the presence of hydrogen sulphide.

Kevin-Sunburst dome.—The surface formation in the Kevin-Sunburst field is the Colorado shale, the maximum thickness being about 1,200 feet. A small amount of water—5 to 75 barrels a day— is found in the Blackleaf sandy member of the formation. The well represented by analysis 83 found a Blackleaf sand at a depth of 1,010–1,015 feet, and that of analysis 84 found two sands at depths of 815–820 feet and 1,200 feet, respectively.

The water in the Colorado shale at Kevin-Sunburst is a concentrated, saline water similar to other Colorado waters already described. It does not enter seriously into production problems, and is differentiated from Sunburst water by its lower alkalinity (3–7 per cent as contrasted to 15–26 per cent for Sunburst water), and from the Ellis and the Madison waters by its much greater concentration and the absence of hydrogen sulphide, which is present in most Ellis and Madison waters.

Devon gas area.—The surface formation at Devon, T. 33 N., R. 2 E., is the Colorado shale and the average thickness drilled is about 1,194 feet. Thelan and Freeman's Johnson well No. 1 encountered a heavy flow of gas at a depth of 797–825 feet, more gas at 888–898 feet, and a water sand at 1,015–1,023 feet. The analysis of this water shows that it is typical Colorado water, moderately concentrated and saline.

SWEETGRASS HILLS FIELDS

Whitlash dome.—The Colorado shale is exposed over the central part of the Whitlash field, but is overlain by as much as 300 feet of glacial drift. The Colorado shale averages 1,845 feet in thickness, and gas and oil are produced commercially from sands in the basal Blackleaf sandy member.

At Whitlash, most of the wells in the Colorado shale yield small amounts of water. However, the only Colorado water analyzed (analysis 86) is from a well producing oil from Blackleaf sands at depths of 1,652–1,693 and 1,790–1,825

feet. The water is moderately concentrated and saline, being chemically similar to Blackleaf waters found elsewhere in the Sweetgrass arch area. However, this water is in contact with oil and may be somewhat more concentrated and more saline than Blackleaf waters encountered elsewhere in the Whitlash field.

The only other water sampled in the Whitlash field likely to be encountered in production problems is from the Ellis formation. This water is less concentrated and has lower salinity and higher alkalinity than Colorado water.

Pinhorn district.—A well on the Pinhorn structure, T. 37 N., R. 6 E., logged the top of the Colorado shale at a depth of about 1,150 feet. At a depth of 2,555–2,560 feet a fine-grained gray water sand was encountered, the water standing 800 feet in the hole. The base of the Colorado was logged at a depth of 2,802 feet.

The water from the aforementioned sand in this well is more dilute than typical Colorado water, and the presence of so much sulphate and normal carbonate suggests contamination by drilling water. The only important difference between upper Eagle and Colorado waters in the Pinhorn well is the total absence of sulphate in the former.

Flat Coulee dome.—The top and bottom of the Colorado shale lie about 500 feet and 2,300 feet, respectively, below the surface in the Flat Coulee structure, T. 37 N., R. 5 E. In one of the three wells drilled on this structure a 15-foot water sand was logged in the middle of the Blackleaf sandy member at a depth of 1,865–1,880 feet, and 15–20 barrels of oil a day, with some gas, were found in a sand at the base of the Blackleaf member.

The Blackleaf water encountered in this well is exceptional for Colorado water, because its bicarbonate content of 5,000 parts per million makes it alkaline instead of saline. Significantly, though, it is rather similar to Blackleaf water in the Pinhorn structure, 5 miles east.

NORTH-CENTRAL FIELDS

Bowdoin dome.—The surface formation at Bowdoin dome, Ts. 31–33 N., Rs. 32–34 E., is the Claggett shale. The top of the Colorado shale lies about 250 feet below the surface, the total thickness of the formation being about 1,800 feet. Three sandy zones in the top of the Colorado contain commercial amounts of gas. The highest (Martin zone) was the original source of gas, but produces none now. The second (Bowdoin zone) is the most important gas zone, and its top lies about 740 feet below the surface. The third (Phillips zone) lies about 250 feet below the Bowdoin zone.

Sample 89 is from a structurally low well and probably represents edge water in the Bowdoin zone. Sample 90 is from the Martin zone in a well drilled only 285 feet deep. Sample 91 is from the Bowdoin zone at a depth of 760–815 feet, and sample 92 is from the Bowdoin zone at an unreported depth.

There seems to be no appreciable difference between waters from the Martin and Bowdoin zones, both being typical Colorado shale water—moderately con-

centrated and saline, the salinity being caused largely by chloride. The sulphate in sample 90 from the Martin zone may be caused by surface-water intrusion, as this zone is very close to the surface. The small amount of sulphate in sample 89 is caused by drilling-water contamination.

One well drilled to the "Quadrant" formation at Bowdoin dome produces large volumes of warm water, which is very high in secondary salinity and differentiated easily from the Colorado waters already described.

CENTRAL FIELDS

Cat Creek anticline.—The Cat Creek field is the largest field in the Big Snowy-Judith Mountain anticlinorium. The principal oil-producing zone is the First Cat Creek sand, a 40–60-foot sandstone near the base of the Colorado shale, though oil is also obtained in the Second Cat Creek sand 160–235 feet lower, in the Kootenai formation. The Colorado shale, which is at the surface, has a total thickness of 1,350 feet, and the base of the coarse-grained First Cat Creek sand zone lies about 50 feet above the Kootenai formation.

The First Cat Creek sand yields oil only on and near the crests of certain domes on the Cat Creek anticline. Elsewhere it yields large volumes of comparatively fresh water under a strong artesian head. Even on the crests of the domes water occurs with the oil, and there are very few wells that are entirely free of water.

All three sands (First Cat Creek sand in the Colorado shale and the Second and Third Cat Creek sands in the Kootenai formation) yield waters so similar that there can be but little doubt that they have a common source.

The Third Cat Creek water (analyses 180–186, Table III) is dilute, usually slightly more alkaline than saline, low in chloride, and has consistent amounts of sulphate,—four to six times as much sulphate as chloride. There is no gas in this sand, and only a trace of oil. The water is used locally for all purposes.

The Second Cat Creek water (analyses 172–179, Table III) is slightly more concentrated than Third sand water, showing a marked increase in alkalinity and a markedly lower sulphate content, but the chloride content is little changed. This water is associated with oil in the sand, but the oil production is far below that of the First Cat Creek sand.

The water from the First Cat Creek sand is more concentrated than either of the lower sands, and has a distinctly higher chloride content, and a bicarbonate content but slightly lower than that of the Second sand water. Sulphate occurs as a trace only.

These analyses suggest that the Third sand is the original reservoir, and that the oil originally in the Third sand was flushed upward into fault-block traps in the Second and First sands by the artesian water of the Third sand, the largest quantity of oil being trapped in the First, or highest, sand. Undoubtedly a large part of the oil originally in the Third sand was flushed out of the anticline by

this artesian water, and the oil now produced from the Cat Creek field is the remnant of a once larger accumulation.

Reeves[9] inclines to the belief that the oil was generated in the overlying Colorado shale, passed into the First sand during the period of compaction of the sediments, and migrated into the Second sand where vertical displacement along fault planes was sufficient to bring the Second sand into contact with the first sand.

Lupton and Lee[10] suggest that the oil was generated in the underlying Ellis and "Quadrant" formations, and migrated upward to the Cat Creek sands along fault planes.

That the Third sand was the original reservoir of the oil, and that the artesian Third sand water was the prime factor in the migration of this oil into the Second and First sands, are suggested by the fact that showings of oil have been found in some wells drilled into the Third sand, and that the waters in the First and Second sands in contact with the oil can be shown to be altered Third sand water.

The sulphate-bearing Third sand water which flushed the oil into the Second and First sands and was consequently trapped with the oil in these sands, has been altered in the Second sand by the change of sulphate to carbonate (Table III). This change of sulphate to carbonate is caused, many authors believe, by the association of sulphate waters with oil, and is widespread in the Upper Cretaceous sands of the Rocky Mountain region.

The First sand water contains only traces of sulphate, suggesting that sulphate-carbonate change has gone as far as it can go. The chloride content of the First sand water is higher than that of the Second and Third sand waters, and is suggestive of the increase in salinity of water in contact with oil noticeable in many oil fields in the Rocky Mountain region. All First sand analyses given in Table II are from wells on the West dome producing both oil and water, except samples 103 and 104, which are from wells on Mosby dome.

The light gravity of the Cat Creek oil (47°–50° A.P.I.) has been cited by Reeves[11] as evidence of its genesis in Cretaceous shales, but fractionation of oil by circulating ground waters has been noted in the Rocky Mountain region[12] and it is not improbable that the high gravity of the Cat Creek oil is a result of this action. The fact that the Second sand oil is about 2° A.P.I. lower in gravity than the First sand oil would seem to support a theory of flushing and fractionating action from below.

[9] Frank Reeves, "Geology of the Cat Creek and Devils Basin Oil Fields and Adjacent Areas in Montana," *U. S. Geol. Survey Bull. 786* (1926), pp. 81–82.

[10] C. T. Lupton and Wallace Lee, "Geology of the Cat Creek Oil Field, Fergus and Garfield Counties, Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 2 (March-April, 1921), pp. 257–58.

[11] Frank Reeves, *op. cit.*, pp. 83–84.

[12] F. M. Van Tuyl and Ben H. Parker, "The Time of Origin and Accumulation of Petroleum," *Colorado School of Mines Quar.*, Vol. 36, No. 2 (1941), pp. 35–36.

First sand water differs from Colorado shale waters previously described in its diluteness and lowered salinity. It can be differentiated from Second and Third sand waters in the Cat Creek field by its chloride content of 300 parts per million or more, and by the absence of sulphate, which characterizes Third sand water.

Devils Basin dome.—At Devils Basin, T. 10 N., R. 25 E., a small quantity of water, estimated at one bailer an hour, was encountered in the First Cat Creek sand at a depth of 885–998 feet in one well. This water is practically sulphate-free, and is more concentrated and more saline than First sand water in the Cat Creek field. The small quantity of water encountered, and its greater concentration, indicates local low permeability of the sand.

SOUTHERN FIELDS

The Colorado shale in the southern fields consists in descending order of (1) Niobrara and Carlile shales; (2) Frontier formation; (3) Mowry and Thermopolis shales. The Frontier formation produces only gas in this area.

Belmont structure.—North of T. 6 N. the Frontier formation is not recognizable. At Belmont, T. 6 N., R. 22 E., however, about 20 feet of sandstone apparently belongs to this formation. The top of this sand, which yields only water, was logged at a depth of 1,815 feet, and the bottom at 1,835 feet. The contained water is essentially a solution of sodium chloride, sulphate being absent, and it bears a strong resemblance to basal Colorado water in the Cut Bank field. It is also similar to Frontier waters in the Powder River basin, Wyoming.

Lake Basin (Big Lake) anticline.—In the Lake Basin field, T. 1 N., R. 21 E., the Frontier consists of about 300 feet of predominantly light-colored sandstone, with some sandy shale and black shale, and its top lies 2,900–3,000 feet below the surface. The formation contains gas, and the four wells drilled can produce a total of 10–15 million cubic feet of gas a day, but have not produced since 1931.

Sample 107 is the only sample of water known to have come from the Frontier in the Lake Basin field, and it is similar to Frontier waters elsewhere, but is concentrated by the evaporative effect of expanding gas. The sample was taken from a line drip, where it picked up calcium and magnesium salts that are probably not present in the water in the sand. This water can be distinguished from Greybull water below by its higher concentration and greater salinity.

Laurel structure.—In the Laurel area, T. 2 S., Rs. 23–24 E., the Frontier consists of about 200 feet of sandstone and sandy shale, the top of the formation being drilled at a depth of about 335 feet. The well from which sample 108 was taken flowed 100 barrels of water a day from the Frontier at a depth of 335–350 feet. The water in this well is fairly dilute and alkaline, and its closest counterpart in Colorado waters is the First Cat Creek water in the Cat Creek field.

One well drilled to the Tensleep sandstone in the Laurel area encountered a large flow of hot water, which can be differentiated easily from Frontier water

by its much higher concentration and the presence of large quantities of calcium and magnesium sulphates.

SUMMARY

The waters from the Blackleaf sandy member of the Colorado shale are ordinarily moderately concentrated to concentrated solutions of sodium chloride, with less than 10 per cent alkalinity. Sulphate is apparently present as surface or drilling-water contamination, and for all practical purposes can be considered as absent.

A moderately dilute, considerably less saline water is yielded by the First Cat Creek sand and Frontier formation in some of the central and southern fields of the state. Although these waters may be associated with oil, as in the Cat Creek field, their character indicates a freedom of flow not found in the Sweetgrass arch area. The First Cat Creek sand water in the Cat Creek field is believed to have originated in the Third Cat Creek (Kootenai formation) sand and to have migrated to the First sand.

There are more connate characteristics in Colorado waters than in the Montana group waters. However, the quantity of water in the Colorado is ordinarily small, which, together with the high concentration and salinity, indicates tight sands and consequent partial retention of connate water.

Upper Cretaceous waters of Wyoming are essentially solutions of sodium chloride and sodium bicarbonate in varying proportions. Sulphate and the alkaline earths are for all practical purposes absent. Colorado waters in Montana bear a definite resemblance to these Wyoming waters. Secondary characteristics are more prevalent in the Montana waters, in three instances secondary salinity being present, which indicates that the softening so noticeable in the Upper Cretaceous Wyoming waters is incomplete. Otherwise, Colorado waters in Montana are similar to Frontier and Shannon waters in Wyoming.

Kootenai Formation Waters

The Kootenai formation, of Lower Cretaceous age, is one of the principal oil- and gas-producing formations in Montana. It includes the Cosmos and Vanalta sands of the Border-Red Coulee field, the Sunburst sand of Cut Bank and Kevin-Sunburst fields, the Cut Bank sand of the Cut Bank field, and the Second and Third Cat Creek sands in central Montana. The formation varies in thickness from 650 feet in the Sweetgrass arch to 250 feet in the southern fields. In the Sweetgrass arch it consists of salt-and-pepper sandstones of variable hardness, sandy variegated mudstones and shale, and carbonaceous shales.

The Kootenai is overlain by the Colorado shale, of Upper Cretaceous age, and is underlain by the Ellis formation of Upper Jurassic age.

SWEETGRASS ARCH FIELDS

Border-Red Coulee nose.—The oil and gas zones in the Border-Red Coulee field occur in the lower part of the Kootenai formation, being lenticular, variable,

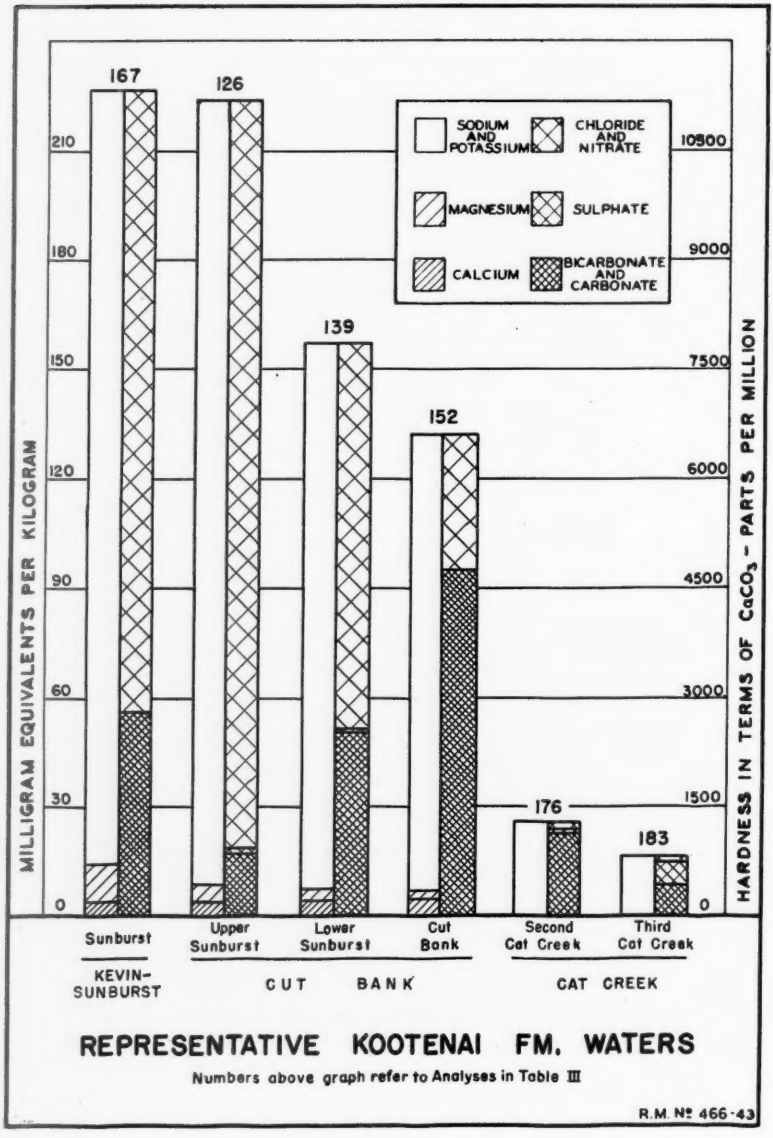

167
126
139
152
176
183
SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
0
30
60
90
120
150
180
210
1500
3000
4500
6000
7500
9000
10500
Sunburst
Upper Sunburst
Lower Sunburst
Cut Bank
Second Cat Creek
Third Cat Creek
KEVIN-SUNBURST
CUT BANK
CAT CREEK
REPRESENTATIVE KOOTENAI FM. WATERS
Numbers above graph refer to Analyses in Table III
R.M. № 466-43

FIG. 5

and otherwise complex sands locally exhibiting a laminated or ribbon structure caused by the intercalation of lenses of black shale. A section of the formation is about as follows: (1) at the top, 400 feet of variegated red, green, and gray shale containing fossil wood, traces of coal, and fresh-water fossils; (2) 10–45 feet of fine, gray sandstone, the Gas sand (upper Sunburst); (3) about 80 feet of blood-red and apple-green bentonitic shale containing two thin local lentils of light gray sand yielding some non-commercial oil and gas; (4) a 10-foot shale break, followed by 0–15 feet of upper Cosmos (Vanalta) sandstone, containing oil, gas, and water; (5) a 10-foot shale break followed by 10–35 feet of gray, coarse sandstone with black chert conglomerate, called the lower Cosmos sand and lithologically identical with the Cut Bank sand of the Cut Bank field.

The Cosmos (Cut Bank) sand is the basal unit of the Kootenai formation in the Border-Red Coulee field, and is the principal producing sand. The upper Cosmos (Vanalta) sand was first thought to be a separate sand body, but later information proved that the Cosmos sand is split over the productive area of the field by a wedge of green bentonitic shale, and that the upper Cosmos is a tongue of the Cosmos sand. Although the terms "Vanalta" and "Cosmos" are still used locally, Erdmann and Schwabrow[13] refer to the undivided basal sand as Cosmos, and to the tongues as the upper Cosmos and lower Cosmos, respectively. The Kootenai averages 525 feet in thickness in this field, and its top lies about 2,000 feet below the surface.

Water analyses from sands in the lower part of the Kootenai at Border-Red Coulee are herein called "Cosmos-Vanalta" waters. The water encountered by drilling wells in the tongues of the Cosmos sand is similar in all respects to that in the basal Cosmos sand. This water is essentially an alkaline water of moderate concentration, sulphate being absent or present in such small amounts that it can be considered as drilling-water contamination. Secondary characteristics are present in minor amounts, ranging from 3 to 14 per cent, and it is noticeable that magnesium ordinarily occupies a greater weight in the chemical system than calcium.

A noteworthy feature of Cosmos-Vanalta waters is the presence of hydrogen sulphide, being the only Kootenai waters in the state which contain this gas. There are two possible explanations: first, the generation of hydrogen sulphide from pyrite in the shale that splits the Cosmos; second, and more logical, the migration of sulphur water from the subjacent Ellis formation. Where Ellis waters have been sampled in northern and north-central Montana, hydrogen sulphide is a characterizing feature. Analyses 198–200, Table V, are Ellis waters from the Border-Red Coulee field, and they are identical with the Cosmos-Vanalta waters in Table III. On the basis of these analyses, it is believed that the gas, oil and water in the Kootenai formation at Border-Red Coulee have migrated upward from the Ellis and accumulated in porous, lenticular zones.

In the Border-Red Coulee field, Cosmos-Vanalta waters and Ellis waters are

[13] Charles E. Erdmann and John R. Schwabrow, *op. cit.*, p. 292.

TABLE III

Kootenai Formation Waters

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS						PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
	COSMOS-VANALTA WATERS:									SWEETGRASS ARCH FIELDS															
109	Border-Red Coulee	1	SW 1	37N	4W	4,105	1,607	19	51	201	650	18	3,170	69.92	0.95	4.19	4.18	18.33	0.60	51.95	29.98	- - -	63.18	6.84	81.46	18.54
*110	Border-Red Coulee	2	SW 1	37N	4W	3,988	1,515	76	52	67	650	- -	3,310	65.92	3.79	4.27	1.40	18.33	- - -	54.25	26.68	- - -	62.42	10.90	92.88	7.12
*111	Border-Red Coulee	1	NE 2	37N	4W	3,767	1,517	70	- -	- -	621	- -	3,170	65.98	3.49	- - -	- - -	17.51	- - -	51.96	25.20	- - -	69.78	5.02	100.00	- - -
*112	Border-Red Coulee	2	NE 2	37N	4W	3,747	1,432	41	70	- -	690	- -	3,160	62.32	2.05	5.76	- - -	18.34	- - -	51.79	26.14	- - -	62.72	11.14	100.00	- - -
*113	Border-Red Coulee	4	NE 2	37N	4W	3,571	1,346	63	48	- -	619	- -	3,000	58.54	4.14	3.95	- - -	17.46	- - -	49.17	26.20	- - -	61.66	12.14	100.00	- - -
*114	Border-Red Coulee	6	NE 2	37N	4W	3,462	1,285	90	52	- -	619	- -	2,880	55.89	4.49	4.28	- - -	17.46	- - -	47.20	27.00	- - -	59.44	13.56	100.00	- - -
*115	Border-Red Coulee	8	NE 2	37N	4W	3,664	1,364	104	48	- -	614	- -	3,120	59.32	5.19	3.95	- - -	17.32	- - -	51.14	25.30	- - -	61.34	13.36	100.00	- - -
*116	Border-Red Coulee	1	SE 2	37N	4W	3,666	1,403	62	51	Tr	650	- -	3,050	61.04	3.10	4.19	- - -	18.34	- - -	49.99	26.84	- - -	62.84	10.68	100.00	- - -
117	Border-Red Coulee	2	SW 2	37N	4W	4,552	1,781	29	74	67	625	- -	4,025	77.47	1.45	6.08	1.40	17.63	- - -	65.97	22.38	- - -	68.76	8.86	92.67	7.33
118	Border-Red Coulee	1	SE 11	37N	4W	5,776	2,360	16	35	64	975	Tr	4,730	102.67	0.80	2.88	1.33	27.50	- - -	77.52	27.12	- - -	69.42	3.46	95.35	4.65
	UPPER SUNBURST WATERS:																								
119	Bob Bank	1	23	36N	5W	12,446	5,015	- -	- -	39	5,670	301	2,890	218.15	- - -	- - -	0.81	159.94	10.03	47.37	73.58	- - -	26.32	- - -	99.51	0.49
120	Cut Bank	2	SW 2	34N	6W	9,903	3,789	73	48	99	5,095	- -	1,625	164.82	3.64	3.95	2.06	143.72	- - -	26.63	84.56	- - -	11.04	4.40	98.58	1.42
121	Cut Bank	1	NW 11	34N	6W	10,800	4,264	35	Tr	- -	5,667	Tr	1,685	185.71	1.75	- - -	- - -	159.85	- - -	27.61	85.28	- - -	13.78	0.94	100.00	- - -
122	Cut Bank	2	NW 11	34N	6W	11,826	4,628	81	Tr	12	6,191	- -	1,850	201.33	4.04	- - -	0.25	174.64	- - -	30.48	85.16	- - -	12.88	1.06	99.86	0.14
123	Cut Bank	1	NW 12	34N	6W	12,633	4,867	89	63	- -	6,333	- -	2,605	211.71	4.44	5.18	- - -	178.64	- - -	42.69	80.72	- - -	14.94	4.34	100.00	- - -
124	Cut Bank	1	NW 14	34N	6W	10,271	3,991	68	48	- -	4,762	- -	2,850	173.70	3.39	3.95	- - -	134.33	- - -	46.71	74.20	- - -	21.74	4.06	100.00	- - -
125	Cut Bank	1	NE 14	34N	6W	11,800	4,612	71	7	44	6,191	- -	1,780	200.61	3.54	0.58	0.92	174.64	- - -	29.17	85.74	- - -	12.26	2.00	99.49	0.51
126	Cut Bank	1	SW 30	34N	6W	12,890	4,938	76	49	58	7,265	Tr	1,005	214.81	3.74	3.45	1.21	204.37	- - -	16.47	92.58	- - -	4.16	3.26	99.41	0.59
127	Cut Bank	1	SE 31	34N	5W	10,786	4,132	56	54	Tr	6,077	- -	950	179.75	2.80	4.44	- - -	171.42	- - -	15.57	91.68	- - -	4.44	3.88	100.00	- - -
128	Cut Bank	1	NE 17	33N	5W	8,484	3,308	36	5	183	4,443	- -	1,035	143.88	1.80	0.41	3.81	125.32	- - -	16.96	88.38	- - -	10.10	1.52	97.08	2.94
129	Cut Bank	1	SE 17	33N	5W	10,759	4,197	59	Tr	96	5,867	- -	1,100	182.56	2.95	- - -	1.98	165.50	- - -	18.03	90.28	- - -	8.14	1.58	98.82	1.18
130	Cut Bank	1	NW 28	33N	5W	13,873	5,494	24	38	40	7,550	Tr	1,600	235.46	1.20	3.14	0.87	213.25	- - -	26.22	89.08	- - -	9.12	1.80	98.62	0.38
131	Cut Bank	1	NW 34	33N	5W	11,930	4,726	23	8	26	6,107	59	1,900	205.60	1.15	0.66	0.58	172.24	1.97	32.62	83.32	- - -	15.80	0.88	99.67	0.33
132	Cut Bank	1	SW 4	32N	5W	12,674	4,813	136	51	46	6,804	- -	1,675	209.36	6.76	4.19	0.96	191.93	- - -	27.45	87.54	- - -	7.48	4.98	99.53	0.47
133	Cut Bank	1	5	32N	5W	11,094	4,220	62	55	303	5,670	- -	1,405	183.55	3.09	4.52	6.19	159.94	- - -	23.03	87.96	- - -	8.06	3.98	95.12	4.88
134	Cut Bank	3	8	32N	5W	13,434	5,200	73	40	20	7,280	- -	1,670	226.18	3.64	3.29	0.42	205.32	- - -	27.37	88.26	- - -	8.76	2.98	99.80	0.20
135	Cut Bank	2	NW 9	32N	5W	11,652	4,249	202	100	27	6,353	- -	1,425	184.83	10.08	8.22	0.56	179.21	- - -	23.36	88.50	- - -	2.50	9.00	98.69	0.31
	LOWER SUNBURST WATERS:																								
136	Cut Bank	1	NW 25	37N	5W	5,159	1,960	79	52	Tr	1,716	- -	2,750	85.24	3.94	4.28	- - -	48.39	- - -	45.07	51.78	- - -	39.42	8.80	100.00	- - -
137	Cut Bank	1	SE 35	35N	6W	8,756	3,504	14	34	28	3,357	- -	3,700	152.41	0.70	2.80	0.58	94.69	- - -	60.64	61.10	- - -	36.66	2.24	99.38	0.62
138	Cut Bank	1	NW 22	34N	7W	7,631	3,086	Tr	- -	51	3,240	- -	2,550	134.24	- - -	- - -	1.06	91.39	- - -	41.79	68.86	- - -	31.14	- - -	98.87	1.13
139	Cut Bank	2	SW 14	34N	6W	8,788	3,427	68	38	32	3,738	- -	3,020	149.08	3.39	3.14	0.67	105.44	- - -	49.50	68.20	- - -	27.60	4.20	99.35	0.65
140	Cut Bank	2	SE 14	34N	6W	10,017	3,888	77	33	42	4,762	- -	2,470	169.14	3.84	3.71	0.87	134.33	- - -	40.49	76.96	- - -	19.32	3.72	99.35	0.65
141	Cut Bank	1	SW 15	34N	6W	8,596	3,299	91	42	Tr	4,023	- -	2,320	143.52	4.54	3.45	- - -	113.48	- - -	38.03	74.90	- - -	19.82	5.28	100.00	- - -
142	Cut Bank	1	SW 2	32N	6W	4,854	1,897	82	Tr	18	1,748	- -	2,255	82.53	4.09	- - -	0.37	48.29	- - -	36.96	57.32	- - -	37.96	4.72	99.27	0.73
	CUT BANK SAND WATERS:																								
143	Cut Bank	1	1	1N	18W	4,441	1,806	18	Tr	217	988	35	2,800	78.54	0.90	- - -	4.51	27.87	1.17	45.89	40.76	- - -	58.10	1.14	86.08	13.92
144	Cut Bank	1	SE 11	37N	5W	6,125	2,462	97	15	- -	1,019	- -	5,150	107.09	4.84	1.23	- - -	28.74	- - -	84.42	55.40	- - -	39.24	5.36	100.00	- - -
145	Cut Bank	1	SW 14	37N	5W	6,037	2,357	87	64	10	1,048	- -	5 025	102.52	4.34	5.26	0.21	29.56	- - -	82.35	56.54	- - -	40.88	8.58	99.32	0.68
146	Cut Bank	1	NE 19	37N	4W	5,793	2,429	18	- -	21	915	Tr	4,900	105.66	0.90	- - -	0.44	25.80	- - -	80.32	24.62	- - -	74.54	0.84	98.34	1.66
147	Cut Bank	1	NW 23	37N	5W	6,080	2,388	71	59	24	1,000	- -	5,100	103.90	3.54	4.85	0.50	28.21	- - -	83.58	24.98	- - -	67.54	7.48	98.24	1.76
148	Cut Bank	1	SW 26	36N	6W	6,770	2,828	- -	- -	- -	1,669	Tr	4,600	123.03	- - -	- - -	- - -	47.63	- - -	75.40	38.72	- - -	61.28	- - -	100.00	- - -
149	Cut Bank	1	34	36N	6W	6,976	2,835	35	Tr	Tr	1,966	- -	4,900	123.31	1.75	- - -	0.58	44.17	- - -	80.31	35.78	- - -	64.82	1.40	98.71	1.29
150	Cut Bank	1	NW 35	36N	6W	7,240	2,904	24	- -	32	1,737	240	4,500	130.22	1.20	- - -	0.67	48.48	8.00	73.77	37.78	- - -	61.30	0.92	98.65	1.35
151	Cut Bank	2	SW 35	36N	6W	8,465	3,582	12	- -	Tr	1,158	- -	7,550	155.82	0.60	- - -	- - -	32.66	- - -	123.76	20.88	- - -	78.74	0.38	100.00	- - -

TABLE III (Continued)
KOOTENAI FORMATION WATERS

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
152	Cut Bank	1	SE 4	36N	5W	7,092	2,866	73	30	- -	1,296	- -	5,750	124.69	3.64	2.47	- - -	36.55	- - -	94.25	27.94	- - -	67.40	4.66	100.00	- - -
153	Cut Bank	1	SE 35	36N	5W	11,224	4,612	- -	- -	132	3,536	240	5,900	200.62	- - -	- - -	2.75	99.74	8.00	90.13	51.10	- - -	48.90	- - -	97.29	2.71
154	Cut Bank	1	W½ 23	36N	5W	12,614	5,035	53	5	51	5,454	- -	4,100	210.04	2.65	0.41	1.06	153.84	- - -	67.20	59.74	- - -	28.88	1.38	99.32	0.68
155	Cut Bank	1	28	36N	5W	11,612	4,663	28	Tr	487	3,976	- -	5,000	202.83	1.40	- - -	10.14	112.15	- - -	81.94	59.88	- - -	39.44	0.68	91.72	8.28
156	Cut Bank	1	SE 32	36N	5W	11,654	4,820	- -	- -	38	3,439	505	5,800	209.67	- - -	- - -	0.79	97.00	16.83	95.05	46.64	- - -	53.36	- - -	99.19	0.81
157	Cut Bank	1	NE 14	35N	6W	8,219	3,338	16	Tr	81	2,952	- -	3,725	145.22	0.80	- - -	1.69	83.28	- - -	61.05	58.20	- - -	41.26	0.54	98.01	1.99
158	Cut Bank	1	SE 21	35N	6W	7,425	3,054	18	- -	Tr	2,214	- -	4,350	132.85	0.90	- - -	- - -	62.45	- - -	71.30	46.70	- - -	52.62	0.68	100.00	- - -
159	Cut Bank	1	23	35N	6W	5,160	1,996	35	- -	808	1,092	- -	8,400	86.85	1.75	- - -	16.83	30.79	- - -	40.08	53.76	- - -	44.26	1.98	64.64	35.36
160	Cut Bank	1	3	34N	6W	7,584	3,098	- -	- -	- -	2,619	- -	3,715	134.77	- - -	- - -	- - -	73.88	- - -	60.89	54.02	- - -	45.16	- - -	100.00	- - -
161	Cut Bank	3	SW 14	34N	6W	4,480	1,779	32	- -	194	1,467	- -	2,050	77.39	1.60	- - -	4.04	41.35	- - -	33.60	57.46	- - -	40.52	2.02	91.09	8.91
162	Cut Bank	1	NE 16	34N	6W	7,225	2,969	- -	- -	90	2,238	- -	3,920	129.25	- - -	- - -	1.87	63.13	- - -	64.25	50.28	- - -	49.72	- - -	97.14	2.86
163	Cut Bank	1	NE 31	31N	4W	4,079	1,668	- -	- -	Tr	1,523	79	1,645	72.55	- - -	- - -	- - -	42.96	2.63	26.96	59.22	- - -	40.78	- - -	100.00	- - -
	SHERBURST WATERS:																									
164	Kevin-Sunburst	1	SE 33	36N	2W	12,511	4,012	45	21	- -	6,450	- -	2,000	213.57	2.25	1.73	- - -	184.76	- - -	32.78	84.80	- - -	13.20	2.00	100.00	- - -
165	Kevin-Sunburst	3	SE 7	35N	2W	10,720	4,180	66	43	52	4,885	- -	3,050	182.01	3.29	3.54	1.08	137.77	- - -	49.99	73.52	- - -	22.86	3.62	99.23	0.77
166	Kevin-Sunburst	1	NW 21	34N	1W	12,074	4,670	66	60	44	5,980	Tr	2,550	203.16	3.29	4.93	0.92	168.66	- - -	41.80	80.22	- - -	19.90	3.88	99.45	0.55
167	Kevin-Sunburst	1	SW 1	33N	1W	12,767	4,865	79	123	- -	6,053	- -	3,350	211.58	3.94	10.11	- - -	170.72	- - -	54.91	75.66	- - -	18.12	6.22	100.00	- - -
168	Pendroy	1	NW 20	27N	5W	14,535	5,439	175	107	45	7,628	- -	2,320	236.62	8.73	8.80	0.94	215.18	- - -	38.03	85.04	- - -	8.06	6.90	99.56	0.44
										NORTH CENTRAL FIELDS																
169	Bull Creek dome	2	SW 2	24N	23E	714	308	- -	- -	- -	35	- -	755	13.36	- - -	- - -	- - -	0.99	- - -	12.37	7.42	- - -	92.58	- - -	100.00	- - -
														CENTRAL FIELDS												
	SECOND CAT CREEK SAND WATERS:																									
170	Bear Creek dome	1	SE 13	17N	23E	825	298	Tr	Tr	360	17	- -	305	12.97	- - -	- - -	7.50	0.48	- - -	4.99	61.20	- - -	38.80	- - -	5.88	94.12
171	Lewistown	1	31	15N	17E	534	15	131	23	243	11	- -	225	0.63	6.54	1.89	5.06	0.31	- - -	3.69	6.96	52.30	- - -	40.74	5.75	94.25
172	Cat Creek	6	NE 12	15N	28E	1,343	572	Tr	Tr	49	35	93	1,215	24.92	- - -	- - -	1.02	0.99	3.09	19.82	8.06	- - -	91.94	- - -	49.38	50.62
173	Cat Creek	5	NE 9	15N	29E	1,191	470	Tr	Tr	242	28	53	810	20.87	- - -	- - -	5.03	0.80	1.76	13.28	27.96	- - -	72.04	- - -	13.81	86.19
174	Cat Creek	6	NW 10	15N	29E	1,005	434	- -	- -	- -	30	Tr	1,100	18.88	- - -	- - -	- - -	0.85	- - -	18.03	4.50	- - -	95.50	- - -	100.00	- - -
175	Cat Creek	5A	SW 10	15N	29E	1,311	512	6	6	17	156	67	1,112	24.42	0.30	0.49	0.35	4.40	2.22	18.24	18.86	- - -	78.18	2.96	92.68	7.32
176	Cat Creek	4	SE 10	15N	29E	1,324	564	Tr	Tr	39	57	- -	1,350	24.56	- - -	- - -	0.81	1.61	- - -	22.14	9.90	- - -	90.10	- - -	66.46	33.54
177	Cat Creek	16	NW 14	15N	29E	1,328	556	6	2	- -	134	80	1,114	24.26	0.30	0.16	- - -	3.78	2.67	18.27	15.30	- - -	82.84	1.86	100.00	- - -
178	Cat Creek	2	NW 21	15N	30E	1,457	622	- -	- -	41	50	53	1,404	27.05	- - -	- - -	0.85	1.41	1.76	23.03	8.32	- - -	91.68	- - -	62.50	37.50
179	Cat Creek	3	NE 21	15N	30E	1,162	487	Tr	- -	Tr	100	- -	1,120	21.18	- - -	- - -	- - -	2.82	- - -	18.36	13.32	- - -	86.68	- - -	100.00	- - -
	THIRD CAT CREEK SAND WATERS:																									
180	Oiltana dome	1	SW 28	16N	28E	939	348	Tr	- -	352	35	Tr	415	15.12	- - -	- - -	7.33	0.99	- - -	6.80	54.80	- - -	45.20	- - -	11.86	88.14
181	Oiltana dome	1	SW 29	16N	28E	828	328	Tr	- -	152	100	Tr	505	14.26	- - -	- - -	3.16	2.82	- - -	8.28	42.00	- - -	58.00	- - -	46.90	53.10
182	Cat Creek	12A	SW 10	15N	29E	801	308	- -	- -	230	38	18	420	13.35	- - -	- - -	4.79	1.07	0.60	6.89	43.88	- - -	56.12	- - -	18.23	81.77
183	Cat Creek	1	NW 15	15N	29E	930	354	- -	- -	289	35	13	486	15.40	- - -	- - -	6.01	0.99	0.43	7.97	46.42	- - -	54.58	- - -	14.14	85.86
184	Cat Creek	1	SE 11	15N	29E	1,014	389	- -	- -	301	35	20	547	16.89	- - -	- - -	6.26	0.99	0.67	8.97	42.94	- - -	57.06	- - -	13.65	86.35
185	Cat Creek	1	SW 21	15N	30E	1,139	420	- -	- -	403	38	33	486	18.52	- - -	- - -	8.38	1.07	1.10	7.97	51.04	- - -	48.96	- - -	11.27	88.73
186	Cat Creek	1	NE 31	15N	30E	544	220	- -	- -	85	30	- -	425	9.58	- - -	- - -	1.77	0.85	- - -	6.97	27.20	- - -	54.60	- - -	32.35	67.65
187	Ivanhoe	1	SW 7	11N	31E	1,396	547	- -	- -	339	51	24	885	23.80	- - -	- - -	7.06	1.44	0.80	14.50	35.72	- - -	64.28	- - -	16.97	83.03

*Hydrogen Sulphide present.

indistinguishable. However, their greater concentration and higher bicarbonate content differentiate both from Eagle waters. The Colorado water in this field is much more concentrated and far more saline than either the Kootenai or Ellis waters, and, in addition, the presence of hydrogen sulphide in the Cosmos-Vanalta water is characteristic.

Cut Bank district.—The Kootenai formation in the Cut Bank field is 520–650 feet thick, the thickening being westward, and the red shale marking the top of the formation lies about 2,000–2,100 feet below the surface. The three sandstone zones near the base of the Kootenai in this field are: (1) upper Sunburst (Moulton) sand, 0–80 feet thick, which is equivalent to the upper Sunburst (Gas sand) of the Border-Red Coulee field, and consists of salt-and-pepper sand of varying hardness that in some places contains oil, or gas, or water; a lenticular lower tongue of this sand is the middle Sunburst sand; (2) lower Sunburst sand, 0–45 feet thick, which is equivalent to the typical Sunburst sand of the Kevin-Sunburst field, and is also of a salt-and-pepper texture of varying hardness, and contains gas, oil, and water; (3) the Cut Bank sand, the principal oil-producing sand in the field and the basal member of the formation; it is 10–70 feet thick, has a salt-and-pepper texture, is of variable hardness, contains black chert at its base, and is the equivalent to the Cosmos sand in the Border-Red Coulee field. The Cut Bank sand contains a very small quantity of water at its base in most of the field, and lies disconformably on the Ellis formation.

Many wells in the Cut Bank field are drilled to the upper Sunburst sand before encountering water, and some do not find water until the Cut Bank sand is penetrated. In other parts of the field water is found in the Blackleaf member of the Colorado shale.

The Kootenai waters can be differentiated from each other, and as they are ordinarily the only waters entering into oil-production problems, a simple field test can be used for their identification. The following table gives the relationship between chloride and bicarbonate in these waters.

Sand	*Average Chloride Content, Parts Per Million*	*Average Bicarbonate Content, Parts Per Million*
Upper Sunburst	6,000	2,000
Lower Sunburst	3,500	2,500
Cut Bank	2,000	4,500

Although these figures are given as an average for Kootenai waters, Table III shows that lower Sunburst and Cut Bank waters become more dilute "off structure" and are recognized with difficulty. However, in the productive parts of the Cut Bank field, their identification is easy.

Upper Sunburst waters in the Cut Bank field are concentrated solutions of sodium chloride and sodium bicarbonate in a ratio of 5 to 1, or greater. There is some resemblance between these waters and Colorado waters in this field, but the average Colorado water has a lower bicarbonate content—ordinarily less than 1,000 parts per million—and consequently higher salinity. Montana group

waters can be recognized easily by their lower concentration and preponderance of sulphate; and Madison waters, containing hydrogen sulphide, are also much lower in concentration than upper Sunburst waters.

Lower Sunburst waters are essentially moderately concentrated solutions of sodium chloride and sodium bicarbonate in an approximate ratio of 2 to 1, or less. Increased alkalinity over that of upper Sunburst water differentiates these waters, and for the same reason lower Sunburst water from the water of the younger Colorado shale. Montana group waters and Madison waters, with their sulphate, need not be confused with lower Sunburst water.

Cut Bank sand waters are moderately concentrated to concentrated solutions of sodium chloride and sodium bicarbonate in the ratio of approximately 1 to 3, sometimes 1 to 2, and less, but ordinarily containing a higher bicarbonate content than chloride. This ratio does not hold strictly true in the gas area and in the southern end of the field, and represents only the average Cut Bank sand water in the productive area. This water is differentiated from both upper and lower waters in the same way as are the Sunburst waters.

The noticeable feature of the Kootenai waters in the Cut Bank field is the decrease of chloride and increase of bicarbonate in the successively lower sandstone members. For this reason it is believed that the water in all three sands had a common source, and that evaporation and concentration by gas have altered the water by increasing the chloride content, and decreasing the bicarbonate content by precipitation and deposition of normal carbonate. This action would go further in the upper Sunburst sand which contains the most gas. It would not go so far, however, in the lower Sunburst which contains less gas and some oil; therefore the chloride is lower and bicarbonate higher than in the upper Sunburst. In the Cut Bank sand, water with or near the oil would be unaffected by these factors, hence the still lower chloride and higher bicarbonate.

Kevin-Sunburst dome.—The Kootenai formation is about 500 feet thick in the Kevin-Sunburst field, the average depth to the top of the formation being about 1,500 feet. The formation consists largely of sandstones, vari-colored shales, and redbeds, with the Sunburst sandstone, 0–50 feet thick and consisting of salt-and-pepper sand grading into sandy shale and calcareous shale, at the base. Just below the Sunburst sand is a band of yellow shale which is used as a stratigraphic marker.

The Sunburst sand is the major gas sand in the Kevin-Sunburst field, and yields oil in the northeastern part. Very little water is found in the sand, but available samples indicate a concentrated, saline water similar to upper Sunburst waters in the Cut Bank field, although the sand itself is equivalent to the lower Sunburst of that field. The effects of the gas in this sand tend toward concentration and salinization of the water. All samples in Table III are from gas wells.

Sunburst water at Kevin-Sunburst is positively differentiated from Colorado shale water only by its greater bicarbonate content, the Colorado water ordinar-

ily having less than 1,500 parts per million. The Ellis and Madison waters in this field are so much more dilute that there can be no difficulty in differentiating them from Sunburst water.

Pendroy nose.—In the Pendroy area, T. 27 N., R. 5 W., just west of the Pondera field, a well struck a small quantity of water at a depth of 2,323–2,332 feet in the Kootenai formation. Although the information on this well is indefinite, it is believed that the water is from the Sunburst sand because the analysis shows concentrated, saline characteristics, very similar to Sunburst water at Cut Bank and Kevin-Sunburst.

NORTH-CENTRAL FIELDS

Bull Creek dome.—The only known Kootenai water analyzed in the north-central area came from a depth of 590 feet in a well on Bull Creek dome, T. 24 N., R. 23 E. The top of the Kootenai was logged at a depth of 300 feet, and the bottom at a depth of 690 feet. The well flowed 70 barrels of potable water a day, but was plugged and abandoned. This water differs from Madison water in this area by its diluteness and by the absence of the alkaline earths and sulphate that are prominent in Madison water.

CENTRAL FIELDS

Bear Creek (Black Butte) dome.—The First Kootenai, or Second Cat Creek, sand yielded the soft, potable water represented by sample 170 at Bear Creek dome, T. 17 N., R. 23 E., at a depth of 800 feet. The water is similar to Third Cat Creek sand water in the Cat Creek field.

Lewistown bench.—A well, drilled by a laundry in Lewistown, T. 15 N., R. 17 E., yields the water represented by sample 171. The water was originally soft, but after several months became hard, at which time sample 171 was taken. It was found that "Quadrant" water from a well 2 miles away was seeping into this well, and after the "Quadrant" well was properly plugged, the Kootenai well again produced soft water. Sample 171 is thus not a representative Kootenai analysis, but does show what an improperly plugged well can do to a formation.

Cat Creek anticline.—Kootenai waters in the Cat Creek field have been discussed in a general manner under Colorado water. The top of the First Kootenai sandstone—the Second Cat Creek sand—is usually logged about 100 feet below the top of the Kootenai, and consists of 10–60 feet of coarse-grained sand, with a shale break in the lower part. The top of this sand is logged at depths of 1,400–1,500 feet below the surface, and yields both oil and water. Eighty-five feet below the base of the Second Cat Creek sand is the top of the thin-bedded Third Cat Creek sand (Second Kootenai sand), which is 60–100 feet thick. This sand yields a large volume of water, showings of oil, and no gas. The water is potable and is used in and near the field for domestic and drilling purposes. The top of the Third Cat Creek sand lies about 1,600 feet below the surface.

Water from the Third Cat Creek sand is the most dilute water in the three sands at Cat Creek, being rather indicative of a freedom of flow sufficient to have flushed any oil or gas from the structure. Sample 186 is the most dilute water from the three sands and the well from which it was taken is situated so far from the top of the structure that it has no connection with the oil and gas field. Third sand water can be distinguished from waters in the two higher sands by its diluteness and the presence of sulphate. Second Cat Creek sand water has a higher bicarbonate content than the Third sand, and a lower chloride content than the First sand.

Ivanhoe structure.—The one test of the Ivanhoe structure, T. 11 N., R. 31 E., logged the top of the Kootenai formation at a depth of 2,626 feet, found the Second Cat Creek sand at 2,654–2,660 feet, and the Third Cat Creek sand at 2,850 feet. The well stopped drilling in the Third sand with water flowing, after having had showings of oil in the upper 5 feet of that sand.

The water yielded by the Third sand is similar to Third Cat Creek water in the Cat Creek field, except that it is somewhat more concentrated, indicating a rather more restricted water movement in this structure. Showings of oil in the upper part of the sand are probably remnants of an oil body that has been flushed from the structure.

SUMMARY

Kootenai formation waters are, in general, moderately concentrated to concentrated waters in which sodium chloride and sodium bicarbonate are the predominant dissolved salts. They resemble Colorado waters in some respects, but ordinarily are more alkaline, which is a criterion for recognizing them. Kootenai waters, at least in two instances, also show migratory characteristics. The Cosmos-Vanalta waters in the Border-Red Coulee field are the only Kootenai waters in the state that contain hydrogen sulphide, and this, together with their similarity to Ellis waters in that field, is evidence that they have migrated with the oil and gas from the underlying Ellis formation. Kootenai waters from the Cut Bank field show decreasing chloride and increasing bicarbonate content in successively lower sandstone members of the formation.

In the central fields of the state, the Kootenai waters are moderately dilute to dilute solutions of sodium salts in some of which sulphate is prominent These waters are seldom associated with oil or gas, and find their counterpart in those relatively shallow Lower Cretaceous waters in Wyoming which are also unassociated with oil or gas.

Cloverly Formation Waters

The Cloverly formation, of Lower Cretaceous age, is closely equivalent to the Kootenai formation, and occurs in south-central, southern, and eastern Montana. It includes the Greybull sandstone member at the top and the Pryor conglomerate member at the base. It underlies the Thermopolis shale, overlies the Morrison formation, and is 250–290 feet thick in the fields hereinafter described.

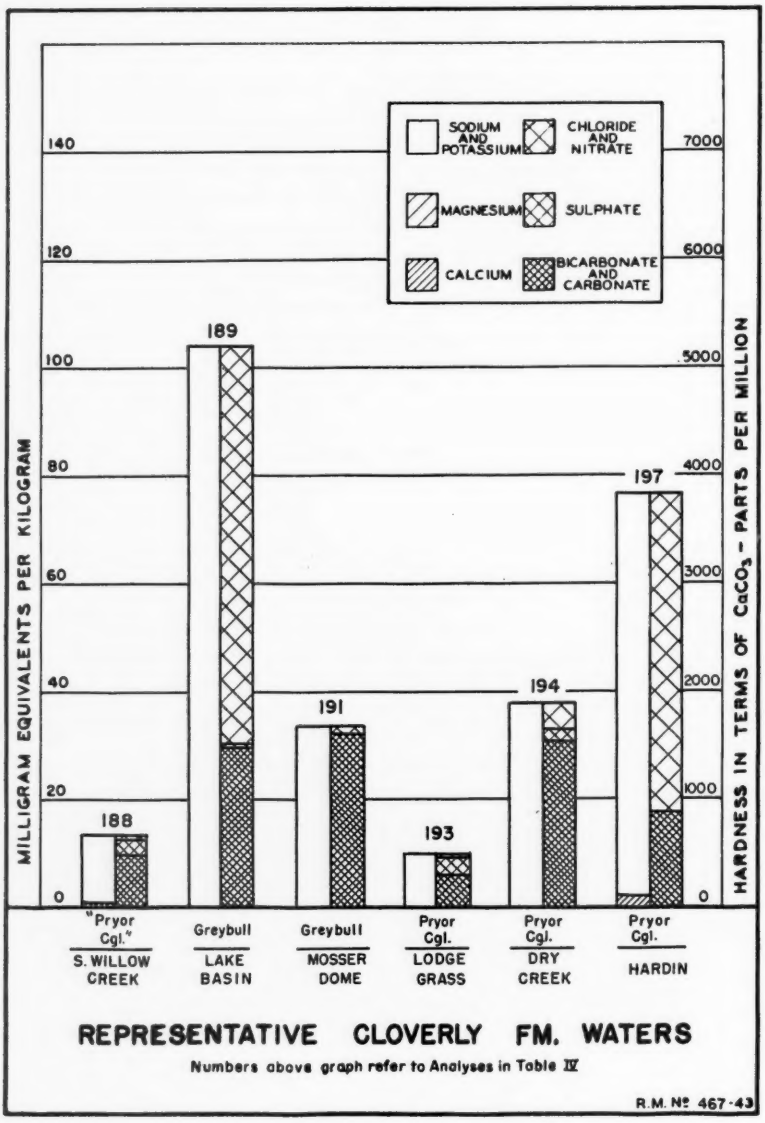

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
140
120
100
80
60
40
20
0
7000
6000
5000
4000
3000
2000
1000
0
188
189
191
193
194
197
"Pryor Cgl."
S. WILLOW CREEK
Greybull
LAKE BASIN
Greybull
MOSSER DOME
Pryor Cgl.
LODGE GRASS
Pryor Cgl.
DRY CREEK
Pryor Cgl.
HARDIN
REPRESENTATIVE CLOVERLY FM. WATERS
Numbers above graph refer to Analyses in Table IV
R.M. Nº 467-43

FIG. 6

TABLE IV
Cloverly Formation Waters

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
											CENTRAL FIELDS																
188	South Willow Creek ("Lakota")	1	NE 20	11N	23E	739	262	15	Tr	136	11	- -	600	12.22	0.75	- - -	2.83	0.31	- - -	9.83	24.22	- - -	70.00	5.78	9.91	90.09
											SOUTHERN FIELDS																
189	Lake Basin (Greybull)	1	SW 24	1N	21E	5,899	2,381	- -	- -	31	2,600	Tr	1,805	103.56	- - -	- - -	0.65	73.33	- - -	29.58	71.44	- - -	28.56	- - -	99.12	0.88
190	McLeod dome (Cloverly)	1	NW 15	2S	13E	1,955	14	436	95	1,342	2	- -	134	0.62	21.77	7.81	27.94	0.06	- - -	2.20	2.06	90.66	- - -	7.28	0.21	99.79
191	Mosser dome (Greybull)	1	NE 26	3S	24E	1,767	765	- -	- -	- -	43	Tr	1,950	33.17	- - -	- - -	- - -	1.21	- - -	31.96	3.64	- - -	96.36	- - -	100.00	- - -
192	Ingersoll (Pryor conglomerate)	1	SE 25	5S	17E	1,790	606	27	Tr	859	38	- -	530	26.29	1.35	- - -	17.89	1.07	- - -	8.68	68.50	- - -	26.52	4.88	5.65	94.35
193	Lodge Grass (Pryor conglomerate)	2	SE 21	6S	35E	544	209	- -	- -	162	7	18	300	9.09	- - -	- - -	3.37	0.20	0.60	4.92	39.28	- - -	60.72	- - -	5.50	94.40
194	Dry Creek (Pryor conglomerate)	9	2	7S	21E	2,065	869	- -	- -	90	179	Tr	1,885	37.81	- - -	- - -	1.87	5.05	- - -	30.89	18.30	- - -	81.70	- - -	72.98	27.02
195	Dry Creek (Pryor conglomerate)	11	4	7S	21E	1,905	804	- -	- -	84	135	120	1,550	34.97	- - -	- - -	1.75	3.81	4.00	25.41	15.90	- - -	84.10	- - -	68.52	31.48
196	Dry Creek (Pryor conglomerate)	6	11	7S	21E	2,419	1,017	- -	- -	95	255	120	1,895	44.23	- - -	- - -	1.98	7.19	4.00	31.06	20.74	- - -	79.26	- - -	78.38	21.62
197	Hardin (Pryor conglomerate)	1	SE 13	1S	33E	4,331	1,709	32	- -	- -	2,074	- -	1,050	74.12	1.60	- - -	- - -	58.51	- - -	17.21	77.28	- - -	20.60	2.12	100.00	- - -

CENTRAL FIELDS

South Willow Creek dome.—The Cloverly formation crops out in the foothills of the Big Snowy Mountains 15 miles west of the South Willow Creek dome, which lies in T. 11 N., R. 23 E. The first well drilled on the dome found artesian water in the "Lakota (Pryor conglomerate)" at a depth of 649–733 feet, the flow measuring 42,750 barrels of potable water a day. This well was drilled to 738 feet, and was plugged and abandoned 5 feet in a bentonitic shale. Later other wells were drilled to the "Lakota" sand on this dome to obtain artesian water. The water is dilute, rather soft, and potable. "Quadrant" water in the South Willow Creek field is characterized by its greater concentration and its dominantly secondary saline character.

SOUTHERN FIELDS

Lake Basin (Big Lake) anticline.—The Cloverly formation is about 250 feet thick in the Lake Basin field, T. 1 N., R. 21 E. It consists of the 100-foot Greybull sandstone member at the top from which comes the only oil produced in the field, and 150 feet of variegated shale, gray sandstone, and conglomeratic basal sandstone. Sample 189 is the only known Cloverly water analyzed from Lake Basin. The well from which the sample was obtained logged the top of the Cloverly at a depth of 3,853 feet, and was completed, producing 50 barrels of clean oil per day at a depth of 3,858–3,869 feet in the Greybull sandstone member. However, production decreased rapidly to an average of ½ barrel of oil with 2 barrels of water a day, and the well is now plugged and abandoned. The Greybull water from this well (analysis 189) is the most concentrated water reported from the Greybull sand, its high salinity doubtless being caused by close association with oil. It is so much more dilute than the concentrated saline water found in the gas-producing Frontier formation in this field that there is no difficulty in differentiating them.

McLeod dome.—Only two wells have been drilled on McLeod dome, T. 2 S., R. 13 E., one, a shallow well which was abandoned in the Virgelle sandstone, and another from which analysis 190 was taken. The latter well was drilled to 2,260 feet, stopping, it is believed, in the Cloverly, where flowing warm water was encountered. The water is moderately dilute, but 90 per cent of the chemical system is calcium and magnesium sulphate. This is the only Cloverly water analyzed from Montana or Wyoming containing such a high percentage of calcium sulphate, and its resemblance to Tensleep waters (Table VI) is very close. For this reason it is believed that this water has migrated upward from the Tensleep, or equivalent beds, or that the well is bottomed in the Tensleep sandstone.

Mosser dome.—The top of the Greybull sandstone member of the Cloverly was logged at a depth of 990 feet and the bottom at 1,035 feet in the non-commercial well on Mosser dome, T. 3 S., R. 24 E., from which sample 191 was taken. The water from the Greybull sand is a moderately dilute solution of sodium bicarbonate.

TABLE V
Ellis Formation Waters

Number	LOCATION					PARTS PER MILLION							MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
						SWEETGRASS ARCH and SWEETGRASS HILLS FIELDS																					
*198	Border-Red Coulee	2	SW 1	37N	4W	3,331	1,305	20	44	54	650	Tr	2,560	56.78	1.00	3.62	1.12	18.33	- - -	41.95	31.68	- - -	60.80	7.52	94.25	5.75
199	Border-Red Coulee	1	SE 2	37N	4W	4,589	1,753	79	70	- -	700	- -	4,040	76.27	3.94	5.76	- - -	19.75	- - -	66.22	22.98	- - -	65.74	11.28	100.00	- - -
200	Border-Red Coulee	1	NW 13	37N	4W	3,881	1,577	24	13	66	755	- -	2,940	68.59	1.20	1.07	1.37	21.30	- - -	48.19	32.00	- - -	64.80	3.20	93.94	6.06
*201	Kevin-Sunburst	3	SW 14	35N	3W	3,753	1,575	Tr	- -	35	712	- -	2,930	68.50	- - -	- - -	0.73	20.08	- - -	47.69	30.38	- - -	69.62	- - -	96.49	3.51
*202	Kevin-Sunburst	1	NW 21	35N	3W	3,293	1,210	16	48	511	695	66	1,519	52.59	0.80	3.95	10.64	19.60	2.20	34.91	52.74	- - -	38.98	8.28	84.85	35.15
*203	Kevin-Sunburst	2	NW 22	35N	3W	3,296	1,187	Tr	- -	- -	648	- -	2,665	60.32	- - -	- - -	- - -	18.27	- - -	42.05	30.28	- - -	69.72	- - -	100.00	- - -
*204	Kevin-Sunburst	1	SE 23	35N	3W	3,070	1,290	Tr	- -	- -	629	- -	2,440	56.10	- - -	- - -	- - -	17.74	- - -	38.36	31.62	- - -	68.38	- - -	100.00	- - -
*205	Kevin-Sunburst	1	NE 25	35N	3W	2,837	1,170	8	3	7	700	- -	1,915	50.89	0.40	0.25	0.15	19.75	- - -	31.64	38.60	- - -	60.20	1.20	99.28	0.72
*206	Kevin-Sunburst	1	NW 26	35N	3W	3,417	1,398	16	- -	109	738	- -	2,350	60.81	0.80	- - -	2.27	20.82	- - -	36.52	37.48	- - -	61.22	1.30	90.18	9.82
*207	Kevin-Sunburst	2	NW 25	35N	3W	3,644	1,441	28	- -	96	762	Tr	2,475	62.67	1.40	- - -	2.00	21.50	- - -	40.57	36.70	- - -	61.12	2.18	91.50	8.50
*208	Kevin-Sunburst	8	NE 28	35N	3W	3,127	1,188	54	37	51	690	- -	2,250	51.66	2.70	3.04	1.06	19.46	- - -	35.88	35.74	- - -	54.26	10.00	94.86	5.14
*209	Kevin-Sunburst	2	NW 31	35N	3W	3,283	1,220	63	15	382	757	- -	1,700	53.09	3.14	1.23	7.96	21.64	- - -	27.86	51.52	- - -	40.88	7.60	73.10	26.90
*210	Kevin-Sunburst	1	SW 32	35N	3W	3,346	1,205	42	48	586	908	- -	1,050	52.45	2.10	3.95	12.19	14.33	- - -	31.98	45.34	- - -	44.32	10.34	54.04	45.96
*211	Kevin-Sunburst	4	NW 4	35N	2W	3,614	1,425	66	20	62	440	- -	3,255	62.05	3.29	1.64	1.29	12.31	- - -	53.36	20.28	- - -	72.36	7.36	90.53	9.47
*212	Kevin-Sunburst	1	SW 5	35N	2W	3,958	1,597	61	Tr	Tr	810	- -	3,030	69.47	3.04	- - -	- - -	22.85	- - -	49.66	30.52	- - -	64.28	4.20	100.00	- - -
*213	Kevin-Sunburst	4	NW 8	35N	2W	3,685	1,446	38	35	Tr	888	- -	2,600	62.88	1.90	2.88	- - -	25.05	- - -	42.61	37.02	- - -	55.92	7.06	100.00	- - -
*214	Kevin-Sunburst	2	NW 11	35N	2W	4,823	2,032	Tr	- -	23	850	- -	3,900	88.37	- - -	- - -	0.48	23.97	- - -	53.92	27.66	- - -	72.34	- - -	98.06	1.94
*215	Kevin-Sunburst	8	SW 11	35N	2W	3,994	1,648	Tr	- -	182	832	- -	2,710	71.67	- - -	- - -	3.79	23.47	- - -	44.41	38.04	- - -	61.96	- - -	86.09	13.91
*216	Kevin-Sunburst	1	SW 20	35N	2W	3,536	1,288	68	70	40	934	- -	2,310	55.89	3.39	5.76	0.83	26.35	- - -	37.86	41.80	- - -	44.12	14.08	96.92	3.08
*217	Kevin-Sunburst	2	SW 20	35N	2W	3,318	1,230	57	59	38	788	- -	2,330	53.51	2.85	4.85	0.79	22.23	- - -	38.19	37.60	- - -	49.82	12.58	96.59	3.41
*218	Kevin-Sunburst	1	SW 24	35N	2W	3,757	1,581	- -	- -	Tr	738	Tr	2,925	68.76	- - -	- - -	- - -	20.82	- - -	47.94	30.28	- - -	69.72	- - -	100.00	- - -
*219	Kevin-Sunburst	1	NE 26	35N	2W	3,543	1,368	78	28	- -	638	- -	2,910	59.49	3.89	2.30	- - -	17.99	- - -	47.69	27.38	- - -	63.20	9.42	100.00	- - -
*220	Kevin-Sunburst	7	SW 25	35N	2W	3,596	1,370	30	62	76	775	- -	2,610	59.62	1.50	5.10	1.58	21.86	- - -	42.78	35.40	- - -	54.64	9.96	93.28	6.72
*221	Kevin-Sunburst	2	SW 33	35N	2W	2,802	1,112	36	15	12	575	- -	2,135	48.33	1.80	1.23	0.25	16.22	- - -	34.99	32.00	- - -	62.00	6.00	98.50	1.50
*222	Kevin-Sunburst	4	NE 34	35N	2W	2,772	1,121	20	7	40	650	- -	1,950	48.75	1.00	0.58	0.83	18.34	- - -	31.14	37.90	- - -	59.38	2.72	95.78	4.22
*223	Kevin-Sunburst	12A	NE 34	35N	2W	2,951	1,177	40	16	11	650	- -	2,170	51.15	2.00	0.99	0.23	18.34	- - -	35.57	34.40	- - -	60.00	5.60	98.84	1.16
*224	Kevin-Sunburst	1	SW 20	35N	1W	3,823	1,317	9	- -	175	643	120	1,950	57.29	0.45	- - -	3.64	18.14	4.00	31.96	37.72	- - -	61.50	0.78	83.30	16.70
*225	Kevin-Sunburst	1	SW 20	35N	1W	3,481	1,265	88	71	- -	643	- -	2,875	55.03	4.39	5.84	- - -	18.14	- - -	47.12	27.80	- - -	56.52	15.68	100.00	- - -
*226	Kevin-Sunburst	6	SW 20	35N	1W	3,507	1,309	74	60	- -	638	- -	2,900	56.91	3.69	4.93	- - -	18.00	- - -	47.53	27.46	- - -	59.38	13.16	100.00	- - -
*227	Kevin-Sunburst	7	SW 20	35N	1W	3,331	1,190	88	79	- -	610	- -	2,775	51.79	4.39	6.50	- - -	17.20	- - -	45.48	27.44	- - -	55.18	17.38	100.00	- - -
*228	Kevin-Sunburst	8	SW 20	35N	1W	3,552	1,324	82	57	- -	638	- -	2,950	57.57	4.09	4.69	- - -	18.00	- - -	48.35	27.14	- - -	59.64	13.22	100.00	- - -
*229	Kevin-Sunburst	1	NW 21	35N	1W	2,998	1,135	54	39	57	565	- -	2,330	49.43	2.70	3.21	1.19	15.96	- - -	38.19	31.00	- - -	58.32	10.68	93.03	6.97
*230	Kevin-Sunburst	2	NW 30	35N	1W	4,015	1,530	80	44	33	801	597	1,890	66.55	3.99	3.62	0.69	22.59	19.88	31.00	31.40	- - -	58.34	10.26	97.01	2.99
*231	Kevin-Sunburst	5	NW 31	35N	1W	3,398	1,265	78	33	32	740	- -	2,500	55.91	3.89	2.71	0.57	20.87	- - -	40.97	34.48	- - -	64.52	10.90	96.40	3.60
*232	Kevin-Sunburst	1	NW 3	34N	4W	2,857	1,185	Tr	- -	69	639	49	1,860	51.58	- - -	- - -	1.44	18.03	1.63	30.48	37.76	- - -	62.24	- - -	92.57	7.43
*233	Kevin-Sunburst	1	NE 3	34N	4W	3,531	1,653	Tr	- -	- -	632	59	1,535	71.91	- - -	- - -	- - -	17.82	1.97	25.16	24.78	- - -	75.22	- - -	100.00	- - -
*234	Kevin-Sunburst	1	SW 3	34N	4W	4,090	1,750	Tr	- -	67	721	170	2,150	76.53	- - -	- - -	1.39	20.33	12.33	35.24	28.38	- - -	71.62	- - -	93.61	6.39
*235	Kevin-Sunburst	1	SW 1	34N	2W	3,402	1,442	Tr	- -	281	369	Tr	2,825	62.75	- - -	- - -	6.04	10.41	- - -	46.30	26.22	- - -	73.78	- - -	63.20	36.71
*236	Kevin-Sunburst	2	1	34N	2W	3,451	1,466	64	30	44	709	567	1,077	65.30	3.19	3.21	0.92	20.19	18.55	13.44	29.56	- - -	61.56	8.78	95.62	4.38
*237	Kevin-Sunburst	10	NW 4	34N	2W	2,785	1,035	72	30	115	425	- -	2,251	45.14	3.59	2.57	2.30	11.99	- - -	36.42	28.00	- - -	59.96	12.04	83.36	16.64
*238	Kevin-Sunburst	2	SE 5	34N	2W	3,355	1,268	68	47	30	550	- -	2,650	55.13	3.39	3.87	0.62	18.34	- - -	43.43	30.40	- - -	57.96	11.64	96.71	3.29
*239	Kevin-Sunburst	4	SW 5	34N	2W	3,280	1,255	32	48	39	654	- -	2,595	65.00	1.60	3.95	0.41	18.45	- - -	41.38	31.76	- - -	59.08	9.16	95.78	4.22
*240	Kevin-Sunburst	6	SE 5	34N	2W	2,536	866	22	46	277	442	120	1,225	38.55	1.10	3.78	5.76	13.49	4.00	20.08	44.56	- - -	44.20	11.24	70.24	29.76
*241	Kevin-Sunburst	1	NW 7	34N	2W	7,252	2,935	16	Tr	- -	2,885	Tr	2,880	127.79	0.80	- - -	- - -	81.39	- - -	47.20	63.30	- - -	36.08	0.62	100.00	- - -
*242	Kevin-Sunburst	1	NW 8	34N	2W	4,436	1,741	88	Tr	76	1,114	- -	2,840	75.73	4.39	- - -	1.58	31.99	- - -	46.55	41.90	- - -	52.62	5.48	95.29	4.71
243	Kevin-Sunburst	21	SW 6	34N	1W	7,531	3,135	Tr	- -	12	2,350	- -	4,340	137.67	- - -	- - -	0.25	66.29	- - -	71.13	48.26	- - -	51.72	- - -	99.67	0.33
*244	Kevin-Sunburst	3	SW 7	34N	1W	4,136	1,614	45	39	88	875	- -	3,000	70.22	2.25	3.21	1.83	24.68	- - -	49.17	35.02	- - -	57.78	7.20	93.09	6.91
*245	Kevin-Sunburst	3	SW 26	34N	1W	3,383	1,380	32	Tr	42	700	- -	2,500	60.00	1.60	- - -	0.87	19.75	- - -	40.98	33.42	- - -	63.98	2.60	95.75	4.25
245	Whitlash *Hydrogen sulphide present	1	NW 26	37N	4E	4,565	1,759	10	- -	821	1,154	- -	1,670	76.52	0.50	- - -	17.10	32.55	- - -	27.37	64.46	- - -	34.90	0.64	66.56	34.44

Ingersoll dome.—The Pryor conglomerate member at the base of the Cloverly formation was logged in one well on this dome, T. 5 S., R. 17 E., at a depth of 3,235–3,258 feet, and consisted of gray conglomeratic sandstone and chert containing a showing of heavy, black oil, and a large quantity of water. As no free oil was found—the showing occurring only in cores—it is believed that the oil is a residuum after flushing of the sand by water. The water is essentially a solution of sodium sulphate and sodium bicarbonate, has a certain resemblance to some Lakota waters in Wyoming, and is probably a fairly typical Pryor conglomerate water.

Lodge Grass.—Analysis 193 is representative of artesian water found in the Pryor conglomerate at a depth of 3,470–3,506 feet at Lodge Grass, T. 6 S., R. 35 E. The conglomerate crops out in the foothills of the Big Horn and Pryor Mountains, but dips so steeply north and east that it is 3,000 feet below the surface just a few miles from its outcrops. The steep slope of the beds is largely responsible for the potable artesian waters at Lodge Grass.

Dry Creek dome.—The Cloverly formation averages about 274 feet in thickness in the Dry Creek field, T. 7 S., R. 21 E., and consists of the 50-foot Greybull sandstone member, containing oil and gas, an intermediate zone of variegated shale and sandy shale, and 60 feet of Pryor conglomerate, containing oil, gas, and water. The Greybull sandstone member is the principal and more consistent oil producer, but the Pryor conglomerate yields larger wells, and more failures. The top of the Pryor conglomerate lies 5,400–5,850 feet below the surface, this variation in depth being caused by faulting.

Water samples from the Pryor conglomerate member, associated with the oil, indicate a moderately dilute, alkaline type, with small quantities of sulphate present, resembling some Lakota waters in Wyoming.

Hardin plunging anticline.—One well in the Hardin field, T. 1 S., Rs. 32–33 E., found 340 barrels of water per day in the Pryor conglomerate at 2,300–2,318 feet. The water (analysis 197) is saline and resembles the Greybull water at Lake Basin.

SUMMARY

Analyses of waters from the Cloverly formation in Montana are so scattered and so few that even general conclusions about their character can hardly be drawn. Two saline samples are given: Lake Basin (sample 189), where the water is associated with oil, and Hardin (sample 197), where the water is not associated with oil. Two dilute, potable samples are given, and in both instances the water sand cropped out on near-by foothills, artesian conditions resulting. The sample from McLeod dome (analysis 190) seems to be a water that has migrated to the Cloverly from an older formation. Evidences are cited of the flushing action of the water in two domes.

The remaining samples listed show variable characteristics, but in general are moderately dilute, alkaline waters, containing some sulphate, thus correlative somewhat loosely with Cloverly waters in Wyoming.

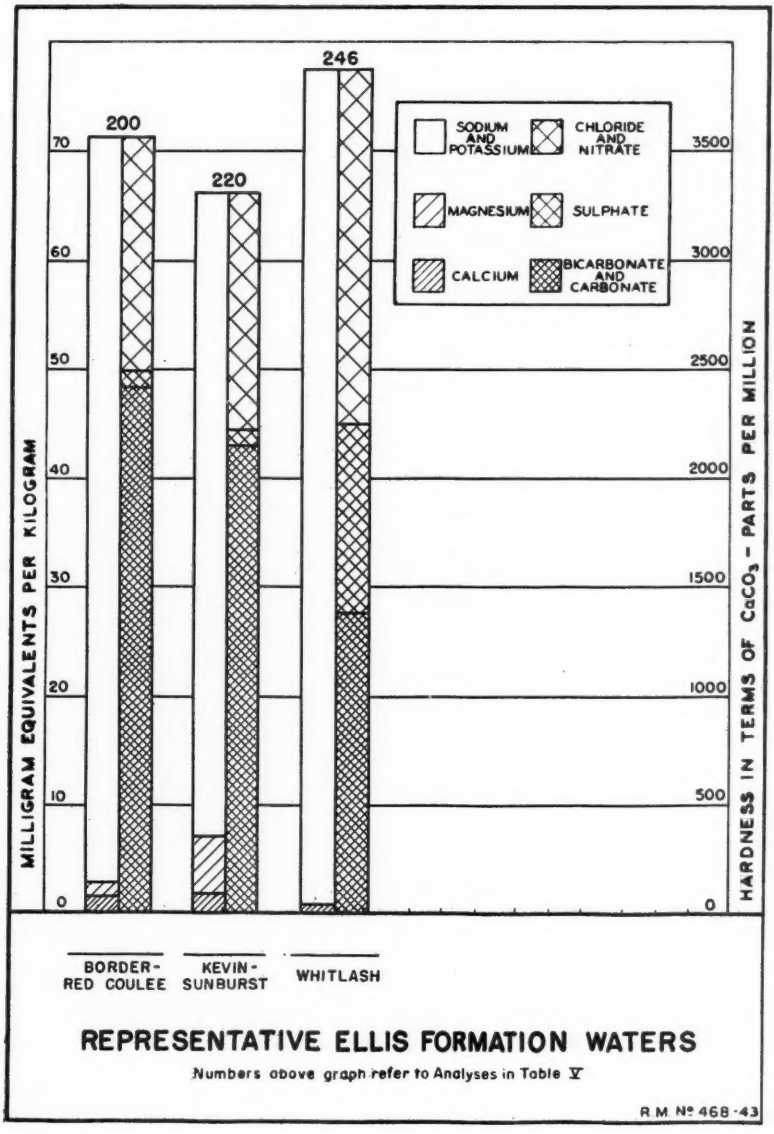

246
200
220
SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
0
10
20
30
40
50
60
70
500
1000
1500
2000
2500
3000
3500
BORDER-RED COULEE
KEVIN-SUNBURST
WHITLASH
REPRESENTATIVE ELLIS FORMATION WATERS
Numbers above graph refer to Analyses in Table V
R.M. Nº 468-43

FIG. 7

Ellis Formation Waters

The Ellis formation, of Upper Jurassic age, lies next below the Kootenai formation in central Montana and in the Sweetgrass arch area, but in the former area it rests on the "Quadrant" formation, of Pennsylvanian and Upper Mississippian age, and in the latter area on the Madison limestone of Lower Mississippian age. It ranges in thickness from 100 to 600 feet and consists largely of black organic limestone and black calcareous shale interbedded with sandstone.

The basal sandstones of the Ellis contain large quantities of sulphur-bearing gas in the northern Sweetgrass arch area but it is not commercially produced. Oil is produced from the Ellis-Madison contact in the Kevin-Sunburst field, and showings of light oil are found in the upper Ellis sands there, but elsewhere in Montana the formation yields only water.

SWEETGRASS ARCH FIELDS

Border-Red Coulee nose.—The Ellis formation in the Border-Red Coulee field consists of 40–225 feet of gray, gray-green, and black calcareous shale and sandy shale, with a gray, coarse, calcareous sandstone of variable thickness (0–120 feet) at the base, which contains only sulphur water.

The three samples of water from the Ellis in the Border-Red Coulee field given in Table V were taken from drilling wells in which all upper waters were shut off. As these samples are practically indistinguishable from the Cosmos-Vanalta (Kootenai) waters listed in Table III, the author believes, as do Dobbin and Erdmann,[14] that the source beds of the oil in the Sweetgrass arch area are the organic limestone and shales in the Ellis formation, that the oil was formed in the Ellis prior to the Laramide revolution, and that it migrated both upward and downward under the influence of water.

Cut Bank district.—The Kootenai rests disconformably on the Ellis in the Cut Bank field, and the Ellis rests disconformably on the Madison limestone. Ninety-five to 295 feet of Ellis beds are present, consisting of gray sandstone, shale, sandy shale, and dark sandy limestone containing no gas, oil, or water. Water found at the base of the Ellis is classed herein as Madison water and included in Table VII.

Kevin-Sunburst dome.—In the Kevin-Sunburst field about 225 feet of Ellis lies disconformably on the Madison limestone, and consists largely of yellowish green and brown calcareous shale and shaly sandstone, and blue-gray calcareous shale. The basal member of the Ellis is 2–50 feet thick, and extremely variable in thickness, composition, and porosity, being largely reworked detritus from the eroded surface of the Madison limestone. This member yields oil, gas, and sulphur-bearing water.

The top of the Ellis formation lies at a depth of about 1,300 feet below the surface in the Kevin-Sunburst field, and the top of the basal sandstone is about 200 feet deeper.

[14] C. E. Dobbin and C. E. Erdmann, "Geologic Occurrence of Oil and Gas in Montana," *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), p. 717.

The water from the basal sandstone member of the Ellis is comparatively uniform throughout the Kevin-Sunburst field. It usually carries a considerable amount of hydrogen sulphide, and has about the same concentration and salinity, whether or not associated with oil. Analyses 241–243 inclusive show abnormally large amounts of chloride, and a study of the logs shows that analysis 241 is from a producing gas well, analysis 242 is from a well that had been acidized, and analysis 243 was contaminated with Sunburst water.

Ellis waters can be differentiated easily from all waters of the younger formations because the latter waters are four to five times as concentrated, far more saline, and contain no hydrogen sulphide. The Madison waters in the Kevin-Sunburst field are somewhat more concentrated than Ellis waters, but are characterized by a considerably higher chloride content and a slightly lower bicarbonate content.

SWEETGRASS HILLS FIELDS

Whitlash dome.—The Ellis formation at Whitlash dome is 180–260 feet thick and consists of gray to black calcareous shales, thin, dark, limestones, and sandstones at its base. The basal sandstone yields sulphur-bearing gas, which is not produced commercially. Ellis water at Whitlash resembles Ellis water at Kevin-Sunburst, though the chloride content is somewhat higher in the former area. Ellis water can be distinguished from glacial drift water at Whitlash by its greater concentration and higher chloride content, and from the Colorado water by its content of sulphate.

SUMMARY

Water from the Ellis formation comes from the basal sandstone member and, in general, is a moderately concentrated solution of sodium chloride and sodium bicarbonate, with alkalinity greater than salinity, and containing 0–20 per cent of calcium and magnesium bicarbonates. Hydrogen sulphide is generally present in appreciable amounts, and sulphate is ordinarily present to some extent, although it may be absent.

The Ellis is the youngest formation water in the state to contain hydrogen sulphide. The Kootenai water in the Border-Red Coulee field contains hydrogen sulphide, but it is thought that this is Ellis water that has migrated to, and been trapped in, the Cosmos sand.

Jurassic waters of Wyoming are the youngest formation waters in that state to contain hydrogen sulphide and are essentially solutions of sodium salts. Ellis waters in Montana are thus correlative favorably with Jurassic waters of Wyoming.

"QUADRANT" FORMATION WATERS

The "Quadrant" formation, of early Pennsylvanian and Upper Mississippian age, consists of marine and non-marine red and black shales, cherty limestones, and sandstones. It is overlain unconformably by the Ellis formation of Upper Jurassic age, underlain conformably by the Madison limestone, of Lower Mis-

TABLE VI

"Quadrant" and Tensleep Formation Waters

Number	Location					Parts per million								Milligram equivalents							Properties of reaction in per cent					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
	"Quadrant" formation waters:																									
										North central fields																
247	Bowdoin Dome	2	SW 35	32N	32E	3,441	269	544	177	2,180	200	--	145	11.71	27.15	14.55	45.39	5.64	---	2.38	21.94	73.60	---	4.46	11.05	88.05
										Central fields																
248	Lewistown	1	NE 20	15N	16E	5,133	1,355	232	54	3,256	140	--	196	58.92	11.58	4.44	67.79	3.95	---	3.20	79.80	17.00	---	4.20	5.43	94.57
249	Flatwillow	2	SE 5	12N	25E	1,845	521	60	34	996	18	--	440	22.67	2.99	2.79	20.73	0.51	---	7.21	74.66	---	5.02	20.32	2.41	97.59
250	South Willow Creek	--	NE 29	11N	23E	4,327	1,025	278	79	2,589	162	--	305	44.58	13.87	6.50	53.90	4.57	---	6.48	68.64	21.38	---	9.98	7.82	92.18
251	Woman's Pocket	1	SW 21	8N	21E	4,020	509	504	132	2,296	285	--	415	22.14	29.65	10.85	47.80	8.04	---	6.80	35.34	53.80	---	10.86	14.40	85.60
252	Porcupine Dome	5	SE 9	10N	39E	3,845	699	486	89	2,189	275	--	340	30.32	21.26	7.32	45.57	7.76	---	5.57	51.48	39.06	---	9.46	14.56	85.44
253	Porcupine Dome	I-X	NW 26	10N	39E	3,995	674	470	104	2,297	288	--	330	29.34	23.46	8.55	47.82	8.12	---	5.41	47.82	43.36	---	8.82	14.52	85.48
254	Porcupine Dome	I-XX	NW 26	10N	39E	4,041	572	547	135	2,192	440	--	315	24.87	27.25	11.10	45.54	12.41	---	5.17	39.34	52.48	---	8.18	21.37	78.63
255	Sixshooter antiocline	1	SW 17	3N	19E	2,471	331	374	64	1,305	225	--	350	14.34	18.66	5.26	27.17	6.35	---	5.74	36.40	49.00	---	14.60	18.97	81.03
256	Hardin	1	SE 13	1S	33E	3,366	364	681	tr	2,166	32	--	230	15.77	33.99	---	45.09	0.90	---	3.77	31.70	60.72	---	7.58	1.95	98.05
	Tensleep sandstone waters:																									
										Southern fields																
257	Laurel structure	1	NE 23	2S	24E	8,470	1,389	287	695	5,539	410	--	305	60.41	14.32	57.15	115.32	11.56	---	5.00	45.80	50.40	---	3.80	9.11	90.89
258	Rye	1	SE 32	4S	16E	3,522	460	670	tr	2,352	38	--	86	20.01	31.45	---	48.97	1.07	---	1.41	38.90	58.38	---	2.72	2.14	97.86
259	Woody Creek	1	NE 33	3S	31E	2,802	34	635	120	1,918	9	--	175	1.40	31.70	9.86	39.93	0.25	---	2.87	3.46	89.88	---	6.66	0.63	99.37
*260	Soap Creek	2	NW 34	6S	32E	2,672	87	628	77	1,688	12	--	365	3.79	31.35	6.33	35.14	0.34	---	5.99	9.14	76.42	---	14.44	0.96	99.04
* 261	Soap Creek	1	NE 34	6S	32E	2,756	64	673	79	1,764	6	--	365	2.79	33.59	6.50	36.72	0.17	---	5.99	6.50	79.54	---	13.96	0.46	99.54

* Hydrogen sulphide present.

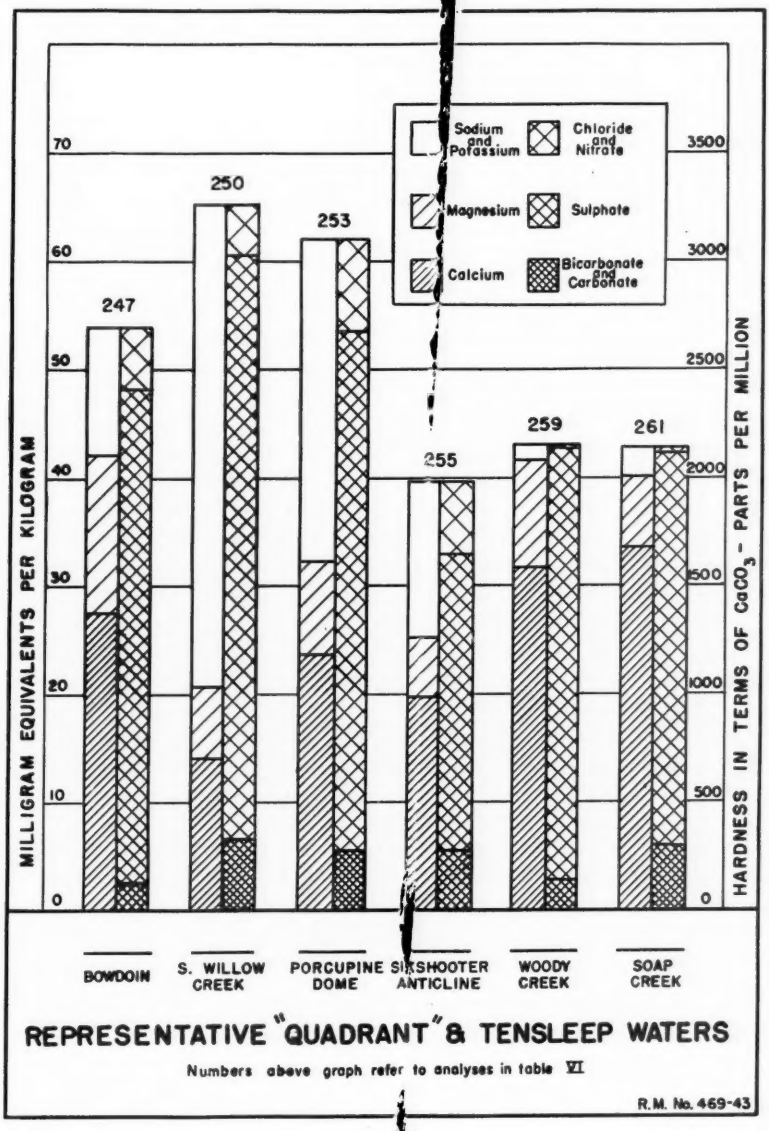

Sodium and Potassium
Chloride and Nitrate
Magnesium
Sulphate
Calcium
Bicarbonate and Carbonate
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
0
10
20
30
40
50
60
70
500
1000
1500
2000
2500
3000
3500
247
250
253
255
259
261
BOWDOIN
S. WILLOW CREEK
PORCUPINE DOME
SHOOTER ANTICLINE
WOODY CREEK
SOAP CREEK
REPRESENTATIVE "QUADRANT" & TENSLEEP WATERS
Numbers above graph refer to analyses in table VI
R.M. No. 469-43

FIG.

sissippian age, and is lithologically similar to the Tensleep sandstone and Amsden formation of southern and eastern Montana. Its maximum thickness in central Montana is 1,700 feet.

It has been pointed out[15] that the Triassic Chugwater formation is the dividing line between the primary waters of younger formations and the secondary waters of older formations in Wyoming. Similarly the "Quadrant" is the dividing line in the Montana oil-field waters, for waters above the "Quadrant" are dominantly primary, and those of the "Quadrant" and older formations are dominantly secondary.

Although the "Quadrant" yields a little oil in central Montana, it ordinarily produces copious quantities of water.

NORTH-CENTRAL FIELDS

Bowdoin dome.—The well from which sample 247 was obtained at Bowdoin dome is one of Montana's best known water wells. This well found the top of the "Quadrant" formation at a depth of 3,071 feet, and a little water between 3,110 and 3,175 feet. At a depth of 3,175–3,180 feet the well flowed about 23,000 barrels of hot water (108°F.) a day. As the well flowed, gas from the Colorado shale at depths of 710–780 feet came from between the 12½- and 15½-inch casing, caught on fire, and burned on the surface of the "Quadrant" water in a pool around the well head. For this reason it was called the "burning well." The American Legion at Malta, Montana, now has a lease on this well and operates a hot-water plunge.

The "Quadrant" water at Bowdoin is essentially a solution of calcium and magnesium sulphates, being a typical "Quadrant" water, which, when fresh, contains a small amount of hydrogen sulphide. This water is differentiated easily from the Colorado water produced with the gas from that formation at Bowdoin, as the secondary characteristics of the "Quadrant" water are diagnostic.

CENTRAL FIELDS

Lewistown bench.—The well from which sample 248 was taken was drilled in the city limits of Lewistown, T. 15 N., R. 18 E. The surface formation is the Kootenai, and water was encountered in dark, hard, fine sand—probably near the base of the "Quadrant"—at a depth of 1,945–1,965 feet. The water has typical "Quadrant" characteristics, but is more concentrated than the ordinary "Quadrant" water.

Flatwillow dome.—In the Flatwillow structure, T. 12 N., R. 25 E., a comparatively dilute water was found in the "Quadrant" formation at 1,839–1,865 feet and at 1,902–1,910 feet in the well from which sample 249 was obtained. The well flowed 15,000 barrels of water a day and was converted into a public reserve. The "Quadrant" crops out in the Big Snowy Mountains 30–50 miles west of the structure. Although the water is comparatively dilute, typical "Quadrant" characteristics are present.

[15] J. G. Crawford, *op. cit.*, p. 1319.

South Willow Creek dome.—In the South Willow Creek area, T. 11 N., R. 23 E., the Pryor conglomerate (Lakota) yields artesian water. One well drilled below the Pryor conglomerate struck artesian water at 1,530–1,540 feet, which is thought to be in the "Quadrant" as the water, represented by analysis 250, has "Quadrant" characteristics. If this well is in the "Quadrant," the Ellis formation is either missing, or very thin. The surface formation at this well is Colorado shale, which was drilled to a depth of about 1,200 feet; the Cloverly formation was drilled at a depth of 1,200–1,300 feet. The Ellis, if present, would be at 1,500–1,525 feet. The "Quadrant" was found at 1,525 feet, and the well bottomed in it at 2,200 feet.

The water represented by analysis 250 is typically "Quadrant," and can be easily differentiated from the artesian Pryor conglomerate water by the greater concentration and dominant sulphate of the former.

Woman's Pocket anticline.—About 1,000 feet of "Quadrant" formation is found in the Woman's Pocket anticline, T. 3 N., R. 21 E. A basal sand in the "Quadrant" at 2,420–2,495 feet yielded 80,000–100,000 barrels of water daily, the quantity of water increasing with depth. The water has typical "Quadrant" characteristics.

Porcupine dome.—The top of the "Quadrant" formation is found at a depth of about 1,480 feet on Porcupine dome, T. 7 N., R. 39 E. About 800 feet below the top of the "Quadrant," water is encountered, and with deeper drilling more water is found. Flows of water ranging from 10,000 to 125,000 barrels daily have been reported. The water has the calcium magnesium sulphate characteristics of "Quadrant" waters found elsewhere in the central area.

Sixshooter anticline.—A well drilled to the basal "Quadrant" at a depth of 4,325 feet on the Sixshooter anticline in T. 3 N., R. 19 E., flowed 10,000 barrels daily of typical "Quadrant" water at a temperature of 157°F. The well was abandoned in a white limestone at a depth of 4,375 feet.

Hardin plunging anticline.—In the Hardin gas field, T. 1 S., Rs. 32–33 E., a flow of water, estimated at 20,000 barrels a day, was yielded by a sand at 3,400–3,415 feet, in the "Quadrant" formation. This field produces gas from the Frontier formation. This same well found water in the Pryor conglomerate which can be differentiated from "Quadrant" water by the absence of sulphate and alkaline earths in the former.

SUMMARY

"Quadrant" waters of north-central and central Montana are the first waters encountered in wells that consistently contain large quantities of sulphate and the alkaline earths. They are also marked by a low bicarbonate content, being strikingly similar in this and other respects to Tensleep waters of Wyoming.

Tensleep Sandstone Waters

The Tensleep sandstone, of Pennsylvanian age, in southern Montana is the lithologic equivalent of the upper part of the "Quadrant" of central Montana.

TABLE VII
Madison Limestone Waters

Number	LOCATION					PARTS PER MILLION								MILLIGRAM EQUIVALENTS							PROPERTIES OF REACTION IN PER CENT					
	Field	Well	Section	Township	Range	Total solids	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Na+K	Ca	Mg	SO_4	Cl	CO_3	HCO_3	Primary Salinity %	Secondary Salinity %	Primary Alkalinity %	Secondary Alkalinity %	Cl Salinity %	SO_4 Salinity %
										SWEETGRASS ARCH FIELDS																
*262	Dunbar	1	SW 22	34N	7W	6,452	2,334	217	64	257	1,177	- -	4,825	101.54	10.83	5.26	5.35	33.20	- - -	79.08	32.78	- - -	53.54	13.68	86.10	13.90
*263	Cut Bank	1	NE 12	33N	6W	2,610	1,074	- -	- -	131	557	- -	1,725	46.71	- - -	- - -	2.73	15.71	- - -	28.27	39.48	- - -	60.52	- - -	84.99	15.01
*264	Cut Bank	1	SW 25	33N	6W	5,026	2,000	- -	- -	225	2,160	120	1,060	86.98	- - -	- - -	4.68	60.93	4.00	17.37	75.44	- - -	24.56	- - -	92.86	7.14
*265	Cut Bank	1	NE 26	33N	6W	3,713	1,454	- -	- -	173	1,928	109	100	62.36	- - -	- - -	3.60	54.39	3.63	1.64	91.66	- - -	8.34	- - -	93.80	6.20
*266	Round Lake	1	SE 28	36N	4W	2.882	1.095	40	40	28	700	- -	1,990	47.66	2.00	3.29	0.58	19.75	- - -	32.62	38.50	- - -	51.60	10.00	97.14	2.86
*267	Kevin-Sunburst	1	SE 11	35N	3W	6,089	2,118	129	132	Tr	2,786	- -	1,880	92.12	6.44	10.85	- - -	78.60	- - -	30.81	71.84	- - -	12.36	15.80	100.00	- - -
*268	Kevin-Sunburst	1	SW 20	36N	2W	3,910	1,169	130	177	Tr	1,658	- -	1,560	50.84	6.04	14.55	- - -	46.77	- - -	25.56	64.66	- - -	5.62	29.72	100.00	- - -
*269	Kevin-Sunburst	1 & 2	SW 20	35N	2W	5,534	1,156	404	334	54	2,975	- -	1,060	50.29	24.66	27.47	1.12	83.03	- - -	17.37	49.10	33.94	- - -	16.96	98.68	1.32
*270	Kevin-Sunburst	2	SW 20	35N	2W	4,057	1,173	200	168	Tr	1,771	- -	1,515	51.00	9.98	13.81	- - -	49.86	- - -	24.83	66.80	- - -	1.40	31.80	100.00	- - -
*271	Kevin-Sunburst	2	SE 9	35N	1W	4,339	961	374	99	72	2,184	- -	1,320	41.81	18.66	8.14	1.50	45.47	- - -	21.64	60.94	7.52	- - -	31.54	96.81	3.19
*272	Pondera (North)	1	SE 20	28N	4W	4,304	1,683	65	28	Tr	1,077	- -	2,950	73.19	3.24	2.30	- - -	30.38	- - -	48.35	38.58	- - -	54.38	7.04	100.00	- - -
*273	Pondera (West)	1	NE 35	27N	5W	3,770	1,283	142	81	40	1,048	- -	2,300	55.82	7.09	6.66	0.83	29.56	- - -	39.18	43.68	- - -	36.56	19.76	97.25	2.75
*274	Pondera	1	SW 15	27N	4W	5,131	1,377	94	427	146	1,150	- -	3,940	60.25	4.60	35.12	3.04	32.44	- - -	64.58	35.60	- - -	24.40	40.00	91.01	8.99
*275	Pondera	1	NE 15	27N	4W	3.576	1,071	40	215	230	1,150	- -	1,770	46.56	2.00	17.68	4.79	32.44	- - -	29.01	56.20	- - -	14.20	29.60	87.54	12.46
										NORTH CENTRAL FIELDS																
276	Loma	1	SE 9	25N	9E	3,333	472	348	163	2,110	120	- -	244	20.54	17.37	13.40	43.93	3.38	- - -	4.00	40.00	51.60	- - -	8.20	7.10	92.81
277	Bull Creek	4	SW 2	24N	23E	2,052	159	296	132	1,285	42	- -	280	6.90	14.77	10.85	26.75	1.18	- - -	4.59	21.22	64.66	- - -	14.12	4.22	95.78
278	Bull Creek	- -	NE 4	24N	24E	1,449	20	278	104	920	19	- -	220	0.89	13.87	8.55	19.16	0.54	- - -	3.61	3.82	80.70	- - -	15.48	2.75	97.25
										CENTRAL FIELDS																
279	Hobson	3	SW 30	14N	15E	736	23	144	70	475	11	- -	230	1.02	7.19	5.76	9.89	0.31	- - -	3.77	7.30	65.72	- - -	26.98	3.05	96.95

* Hydrogen sulphide present.

It consists of 15–80 feet of white sandstone, underlying the Embar limestone and overlying the Amsden formation.

Laurel structure.—The well from which sample 257 was taken is the only well drilled to the Tensleep sand at Laurel, T. 2 S., Rs. 23–24 E. At a depth of 2,360–2,365 feet a light gray sand yielded large volumes of hot water. The flow was not measured, and drilling ceased 5 feet in the sand at a depth of 2,365 feet. The water is a comparatively concentrated, secondary saline water, correlating with "Quadrant" water and Tensleep waters elsewhere, but contains an exceptional amount of magnesium. Excess of magnesium over calcium in proportions as great as in sample 257 indicates a dolomitized formation.

The only other water analyzed from the Laurel structure is Frontier water, found at a depth of about 335 feet. This water is dilute and alkaline, with both alkaline earths and sulphate absent, which differentiates it from secondary saline Tensleep water.

Nye dome.—Typical Tensleep water was encountered at 3,550–3,622 feet in the one well drilled on the Nye dome, T. 4 S., R. 16 E. The Tensleep there consists of vari-colored sands, shales, and hard limestone, and the top was logged at 3,550 feet. Drilling was stopped at 3,661 feet in the Tensleep. After the well was allowed to produce for a few days, the water would flow over the casing.

Woody Creek dome.—The Tensleep sandstone was logged at 2,320–2,402 feet in a well at Woody Creek dome, T. 3 S., R. 31 E., and yielded 15,000 barrels of hot water daily. The well was drilled to 2,755 feet, bottoming in the Madison limestone; and a showing of oil and water was reported in the Amsden formation. Some Amsden water is mixed with the Tensleep water in sample 259, but the amount is too small seriously to affect the characteristics of the Tensleep sample.

Soap Creek dome.—The Tensleep formation at Soap Creek, T. 6 S., R. 32 E., consists of about 25 feet of hard sandstone and limestone and about 30 feet of white sandstone with green shale and variegated limestone and sand. The top of the Tensleep is logged at 1,500–1,520 feet below the surface. Oil is produced in this field from the Tensleep, Amsden, and Madison, and all formations yield abundant quantities of water on the edge of the structure.

There are too few definitely correlated analyses to make rules for differentiating Tensleep, Amsden, and Madison waters, and it is probable that there has been some mingling. The only apparent differences between Tensleep and Amsden waters are the concentration and calcium content, the Amsden water so far analyzed averaging 1,100 parts per million against 2,700 parts per million for the Tensleep; the calcium content in the Amsden water averages only about 150 parts per million against 650 parts per million for Tensleep water. Both waters contain hydrogen sulphide.

SUMMARY

Tensleep waters show the same chemical characteristics as "Quadrant" waters, as would be expected in equivalent formations. Secondary characteristics occupy more than half of the chemical system and in some of the waters more

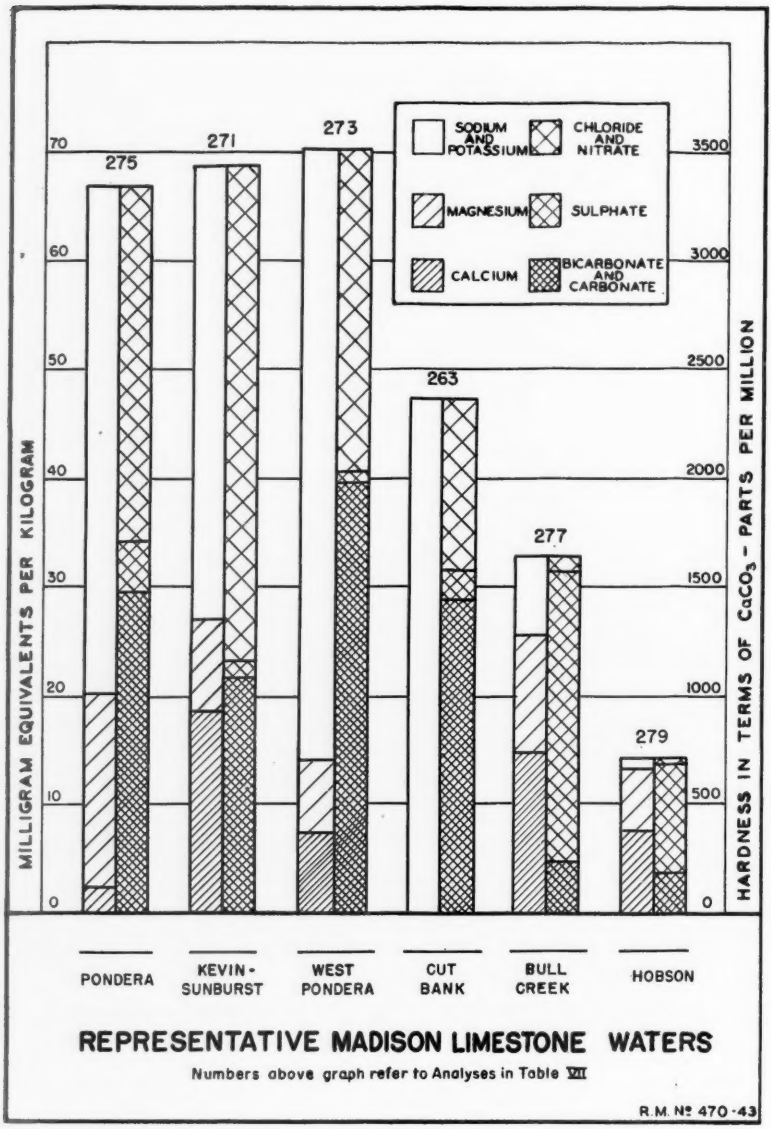

SODIUM AND POTASSIUM
CHLORIDE AND NITRATE
MAGNESIUM
SULPHATE
CALCIUM
BICARBONATE AND CARBONATE
MILLIGRAM EQUIVALENTS PER KILOGRAM
HARDNESS IN TERMS OF $CaCO_3$ - PARTS PER MILLION
0
10
20
30
40
50
60
70
0
500
1000
1500
2000
2500
3000
3500
275
271
273
263
277
279
PONDERA
KEVIN-SUNBURST
WEST PONDERA
CUT BANK
BULL CREEK
HOBSON
REPRESENTATIVE MADISON LIMESTONE WATERS
Numbers above graph refer to Analyses in Table VII
R.M. Nº 470-43

FIG. 9

than 90 per cent. Hydrogen sulphide is present in Tensleep waters from the Soap Creek structure.

Tensleep and "Quadrant" waters of Montana are similar to Tensleep waters of Wyoming, the low bicarbonate content so typical of Tensleep water in Wyoming being a characteristic of Montana waters.

Madison Limestone Waters

The Madison limestone, of Lower Mississippian age, consists of massive gray limestone 700–2,000 feet thick, and in most of the fields in the state has not been entirely penetrated. Except for some unproduced oil found in older beds in deep tests on the Cedar Creek anticline, the Madison is the oldest formation yielding commercial quantities of oil and gas in Montana.

SWEETGRASS ARCH FIELDS

Dunbar nose.—A wildcat test on the Dunbar structure, T. 34 N., R. 7 W., northwest of the important Cut Bank field, logged the top of the Madison at a depth of 3,742 feet, drilled 48 feet into the formation, and was abandoned at a depth of 3,790 feet. Water from the Madison rose 600 feet in the hole, and analysis 262 shows it to be a moderately concentrated, alkaline water resembling other Madison waters in the Sweetgrass arch area, except for its greater than normal bicarbonate content.

Cut Bank district.—The Madison limestone at Cut Bank is overlain disconformably by the Ellis formation of Upper Jurassic age. Presumably more than 1,000 feet of massive gray limestone composes the Madison in this field, although wells have only gone about 100 feet into the formation, finding water at the top. The top of the limestone lies about 3,150 feet below the surface, and water is ordinarily under sufficient head to come within a few hundred feet of the top of the drill hole.

Madison water at Cut Bank varies to a considerable degree in concentration and chloride-bicarbonate ratio, but can always be recognized by the presence of hydrogen sulphide, being the only water in the Cut Bank field to contain this gas. It resembles some of the Kootenai waters, and can only be differentiated from them with certainty by the presence of hydrogen sulphide, or by comparison with analyses from near-by wells.

The old Carnegie-Rigney test in T. 36 N., R. 4 W., about 10 miles south of the Border-Red Coulee field, logged the top of the Madison at 2,917 feet, and at 2,933 feet had 500 feet of water standing in the hole. The well was bottomed in the Madison at 2,990 feet. Sample 266 is from this test.

Kevin-Sunburst dome.—About 770 feet of Madison limestone is present in the Kevin-Sunburst field, the top of the limestone lying about 1,590 feet below the surface. Porous conditions near the top of the Madison are responsible for considerable oil production, and vertical fractures in the lower part yield oil showings. For the most part the Madison consists of white, yellow to light brown,

hard, fine-grained, massive limestone, coarsely crystalline and fossiliferous in the center. The lower part of the formation is tight, hard, and cherty.

All the wells in Table VII were acidized prior to taking the water samples. For this reason it is difficult to determine whether these waters are actually different from Ellis waters just above, or are Ellis waters altered by acidization. The fact that the oil is from the Ellis-Madison contact makes it difficult to determine which formation furnishes the water associated with the oil. The water may be working down from the Ellis into the Madison, or may be working from the Madison up into the Ellis, or both formations may be furnishing it.

Pondera terrace.—The oil production at Pondera, which occupies Ts. 27–28 N., Rs. 4–5 W., is from the dolomitized upper 40 feet of the Madison limestone, the top of which is logged at an average depth of 2,000 feet. The field now produces 600–700 barrels of oil a day from 156 wells, which have an average penetration of 25 feet in the Madison.

Madison waters from this field are somewhat variable, depending largely on structural position. Samples 272 and 273 are from wells outside the oil field and, though essentially similar to samples 274 and 275, which are from the productive area, do not show the excess magnesium present in the two latter samples. Probably the edge of the field is not dolomitized, thus a dolomitized formation is indicated in water analyses by excess magnesium over calcium.

NORTH-CENTRAL FIELDS

Loma structure.—A well, now plugged and abandoned, on the Loma structure, T. 25 N., R. 9 E., logged the top of the Madison limestone at 2,017 feet, was drilled to 2,378 feet in the limestone, and was abandoned. Water, estimated at 15,000 barrels a day, flowed from the well when the drill first entered the Madison.

In the Loma and other north-central fields later described, the Madison water materially differs from Madison water in the Sweetgrass arch fields, in that it is similar to "Quadrant" water. Madison waters in the Sweetgrass arch fields are solutions in which chloride and bicarbonate are the predominant negative radicles and sulphate is low, but in the north-central and central fields sulphate is the dominant negative radicle and chloride and bicarbonate are low.

Bull Creek dome.—The top of the Madison was logged at 1,068 feet in the well on Bull Creek dome, T. 24 N., R. 23 E., from which sample 277 was taken, and the well stopped drilling at 1,115 feet, still in the limestone. The well flowed 20,000 barrels a day from the Madison formation. When the well flowed, a spring 4 miles away at the head of Siperian Creek ceased to flow. One week after the well was closed in, the spring again flowed.

The flow from both the well and the spring was nearly equal to 20,000 barrels a day. Analysis 278 is from the spring, which was sampled approximately 7 months after the well sample was taken. The spring water has about the same calcium and magnesium content as the well water, but is more dilute and thus

considerably lower in primary salinity. Apparently the well water is under artesian head, but is somewhat more stagnant than the spring water, causing increased concentration and greater primary salinity. The spring water is an example of circulating ground water flanking a dome that has trapped the well water. The well being lower structurally than the outlet of the spring, reduced the pressure when allowed to flow so that the spring could not flow.

The Kootenai formation in this same well flowed 70 barrels of potable water a day. However, the Madison water, with its much greater concentration and presence of sulphate and the alkaline earths, can easily be differentiated from the soft Kootenai water.

CENTRAL FIELDS

Hobson structure.—A dilute, potable water flow of 4,000 barrels a day was encountered in the Madison limestone at 1,830–1,870 feet in the Hobson area, T. 14 N., R. 15 E. The well bottomed 40 feet in the limestone and was saved for a water well. The source of the water in the Madison limestone here is the Little Belt Mountains, upon whose slopes the formation crops out. Although dilute, the water has characteristics similar to Madison water in the north-central fields, being essentially a solution of calcium and magnesium salts, with sulphate as the principal negative radicle.

SUMMARY

Madison waters have been analyzed from fields in the Sweetgrass arch area, north-central Montana, and central Montana. Two types of Madison water are noted: (1) those from the Sweetgrass arch and Sweetgrass Hills fields which are essentially solutions of sodium salts, the chloride and bicarbonate being the dominant negative radicles, with definite and appreciable amounts of the alkaline earths and traces to moderate amounts of sulphate; and (2) those from the north-central and central fields which are essentially solutions of calcium and magnesium sulphate, the chloride and bicarbonate radicles being present only in moderate amounts. Extensive acidization in the Sweetgrass arch fields may have affected the composition of the Madison water there to some extent.

CONCLUSIONS

The oil-field waters of Montana, as a whole, are less concentrated than equivalent formation waters in Wyoming, and have undoubtedly been considerably modified by infiltration of surface water. The sedimentary formations from which waters were sampled crop out on the many uplifts and the sands are intakes for abundant quantities of fresh water that have modified, and are now modifying, the connate water originally present in the sands.

The average concentration of the waters associated with oil is about 4,000 parts per million. Concentrated water of 10,000–15,000 parts per million is ordinarily associated with gas, and concentrations of this magnitude can be logically ascribed to the evaporative effect of the gas. In the Cat Creek field of

central Montana a moderately dilute (less than 2,000 parts per million concentration) water is associated with oil. Conversely, there is strong evidence that waters of moderately dilute concentration have flushed oil from certain domes in central and southern Montana.

That water has migrated from one formation to another is considered probable in this state. The writer believes that the only logical explanation for hydrogen sulphide in the Kootenai water at Border-Red Coulee lies in its migration from the underlying Ellis formation. The moderately dilute water associated with the oil in the First Cat Creek sand at Cat Creek is thought to have originated in the Third sand, and flushed the oil from the Third sand into the fault-block traps of the Second and First sands.

A few formation waters are found in Montana in which the magnesium is far in excess of calcium, a feature which is decidedly exceptional in natural waters. In one place (Pondera) it is known that such a water comes from a dolomitized section of the Madison limestone, suggesting that such a feature in a formation water indicates dolomitization of the formation.

Extensive acidization of limestone and calcareous formations in the oil fields of the state has altered the connate water in those areas and one working with these analyses for correlative purposes should be on guard for these altered waters. Acidization is indicated by an abnormal increase in calcium and magnesium chlorides, and this increase may show for months after a well has been put on production.

Upper Cretaceous Montana group waters are dilute to moderately dilute solutions of sodium salts with extensive replacement of connate water by circulating ground waters, particularly in those areas where the sands crop out on or near the structure. Sodium sulphate is ordinarily the dominant salt. In those areas in which gas is commercially produced from the sandstone members, a concentrated, saline water is found, indicating more connate characteristics and evaporative effect of gas.

Upper Cretaceous Colorado waters are moderately concentrated to concentrated saline waters in which sulphate is absent or present in but small amounts, and their concentration and salinity are ascribed to tight sand conditions and partial retention of the connate water.

Lower Cretaceous Kootenai waters resemble Colorado waters in concentration, but are ordinarily more alkaline. Cloverly waters of central and southern Montana are scattered, but several artesian areas are known.

Upper Jurassic Ellis waters resemble Kootenai waters in their chemical characteristics, but ordinarily contain definite quantities of hydrogen sulphide. The Ellis is the youngest formation in the state to contain hydrogen sulphide as an integral part of its water, and may be the source of much of the Kootenai water found associated with oil.

The "Quadrant" and Tensleep formations of central and southern Montana are notable reservoirs of water, yielding flows as high as 125,000 barrels of water

a day. Many areas produce hot water from these formations, and small quantities of hydrogen sulphide are in some places present in the fresh water at the well head. Secondary salinity characterizes these waters.

Madison waters are erratic in composition. Waters of primary characteristics are found in the Sweetgrass arch fields, and secondary characteristics are found in the waters of the north-central and central fields. Acidization of this formation may be the contributory cause of the erratic nature of its waters.

Appendix

The appended table has been prepared as an aid in identifying the various waters likely to be encountered in the oil and gas fields of the state. Those fields in which two or more different formation waters have been analyzed and definitely correlated with known geologic horizons are listed in the table with typical analyses of all formation waters sampled. The fields have been arranged from north to south and west to east, beginning with the Sweetgrass arch fields, and concluding with the southern fields.

APPENDIX

Field and Location	Formations						Remarks
	Montana Group	Colorado Shale	Kootenai Formation	Ellis Formation	"Quadrant" and Tensleep Sandstone	Madison Limestone	
			SWEETGRASS ARCH FIELDS				
BORDER-RED COULEE T. 37 N.—R. 4 W.	*Virgelle* Na 219 Ca 93 Mg 69 SO_4 546 Cl 10 HCO_3 500 T.S. 1,183 *Two Medicine* Na 1,073 Ca 52 Mg 55 SO_4 1,852 Cl 133 HCO_3 700 T.S. 3,509	*Blackleaf* Na 6,203 Ca 39 Mg 43 SO_4 188 Cl 8,800 HCO_3 1,415 T.S. 15,969	*Cosmos-Vanalta* Na 1,285 Ca 90 Mg 52 SO_4 0 Cl 619 HCO_3 2,880 T.S. 3,462 *Upper Sunburst* Na 4,197 Ca 59 Mg Tr SO_4 95 Cl 5,867 HCO_3 1,100 T.S. 10,759 *Lower Sunburst* Na 3,427 Ca 68 Mg 38 SO_4 32 Cl 3,738 HCO_3 3,020 T.S. 8,788	Na 1,577 Ca 24 Mg 13 SO_4 66 Cl 755 HCO_3 2,940 T.S. 3,881	Absent	Not sampled	H_2S present in Cosmos and Ellis waters
CUT BANK T. 37 N.—T. 32 N. R. 7 W.—R. 5 W.	*Virgelle* Na 386 Ca 0 Mg 0 SO_4 265 Cl 14 HCO_3 665 T.S. 992	*Blackleaf* Na 5,706 Ca 126 Mg 35 SO_4 0 Cl 8,572 HCO_3 950 T.S. 14,906	*Cut Bank* Na 2,835 Ca 35 Mg Tr SO_4 28 Cl 1,566 HCO_3 4,900 T.S. 6,874	Does not contain water	Absent	Na 1,074 Ca 0 Mg 0 SO_4 131 Cl 557 HCO_3 1,725 T.S. 2,610	Madison waters contain H_2S, and may be altered to a considerable degree by acidization of limestone

APPENDIX—*Continued*

Field and Location	Formations						*Remarks*
	Montana Group	*Colorado Shale*	*Kootenai Formation*	*Ellis Formation*	*"Quadrant" and Tensleep Sandstone*	*Madison Limestone*	
KEVIN-SUNBURST T. 36 N.—T. 33 N. R. 4 W.—R. 1 W.	Absent	*Blackleaf* Na 5,635 Ca 87 Mg 115 SO_4 72 Cl 8,476 HCO_3 1,120 T.S. 14,936	*Sunburst* Na 4,670 Ca 66 Mg 60 SO_4 44 Cl 5,980 HCO_3 2,550 T.S. 12,074	Na 1,370 Ca 30 Mg 62 SO_4 76 Cl 775 HCO_3 2,610 T.S. 3,596	Absent	Na 1,173 Ca 200 Mg 168 SO_4 Tr Cl 1,771 HCO_3 1,515 T.S. 4,057	H_2S present in Ellis and Madison waters
			SWEETGRASS HILLS FIELDS				
WHITLASH T. 37 N.—R. 4 E.	*Glacial drift* Na 541 Ca 63 Mg 29 SO_4 686 Cl 12 HCO_3 880 T.S. 1,764	*Blackleaf* Na 2,809 Ca 19 Mg 0 SO_4 0 Cl 3,834 HCO_3 915 T.S. 7,112	Not sampled	Na 1,759 Ca 10 Mg 0 SO_4 821 Cl 1,154 HCO_3 1,670 T.S. 4,565	Absent	Not sampled	
PINHORN T. 37 N.—R. 6 E.	*Upper Eagle* Na 624 Ca 0 Mg 0 SO_4 Tr Cl 160 HCO_3 1,390 T.S. 1,463	*Blackleaf* Na 712 Ca 0 Mg 0 SO_4 245 Cl 275 HCO_3 1,120 T.S. 1,776	Not sampled	Not tested	Probably absent	Not tested	
			NORTH-CENTRAL FIELDS				
SIGNAL BUTTE T. 37 N.—R. 15 E.	*Claggett* Na 3,516 Ca 61 Mg 37 SO_4 35 Cl 5,534 HCO_3 135 T.S. 9,249	Dry	Not sampled	Na 1,522 Ca Tr Mg 0 SO_4 0 Cl 410 HCO_3 3,335 T.S. 3,572	Not tested	Not tested	

APPENDIX—*Continued*

Field and Location	Formations						*Remarks*
	Montana Group	*Colorado Shale*	*Kootenai Formation*	*Ellis Formation*	*"Quadrant" and Tensleep Sandstone*	*Madison Limestone*	
BOXELDER T. 32 N.—R. 17 E.	*Judith River* Na 3,466 Ca 46 Mg 20 SO_4 34 Cl 5,304 HCO_3 270 T.S. 9,003 *Virgelle* Na 3,932 Ca 0 Mg 0 SO_4 523 Cl 4,567 HCO_3 1,930 T.S. 9,961	Not tested	Not tested	Not tested	Not tested	Not tested	
BOWDOIN T. 33 N.—T. 31 N. R. 34 E.—R. 32 E.	*Virgelle* Na 553 Ca 57 Mg Tr SO_4 0 Cl 844 HCO_3 190 T.S. 1,547	*Martin* Na 2,676 Ca 54 Mg 39 SO_4 142 Cl 4,000 HCO_3 400 T.S. 7,108 *Bowdoin* Na 3,840 Ca 89 Mg 54 SO_4 47 Cl 6,053 HCO_3 255 T.S. 10,208	Not sampled	Not sampled	*"Quadrant"* Na 269 Ca 544 Mg 177 SO_4 2,180 Cl 200 HCO_3 145 T.S. 3,441	Not tested	Trace of H_2S present in fresh water from "Quadrant" formation

APPENDIX—*Continued*

Field and Location	Formations						*Remarks*
	Montana Group	*Colorado Shale*	*Kootenai Formation*	*Ellis Formation*	*"Quadrant" and Tensleep Sandstone*	*Madison Limestone*	
BULL CREEK T. 24 N.—R. 23 E.	Absent	Surface formation	Na 308 Ca 0 Mg 0 SO_4 0 Cl 35 HCO_3 755 T.S. 714	Not sampled	Not sampled	Na 159 Ca 296 Mg 132 SO_4 1,285 Cl 42 HCO_3 280 T.S. 2,052	
			CENTRAL FIELDS				
CAT CREEK T. 15 N.—R. 28–30 E.	Absent	*First Cat Creek* Na 591 Ca 0 Mg 0 SO_4 0 Cl 400 HCO_3 880 T.S. 1,394	*Second Cat Creek* Na 564 Ca Tr Mg Tr SO_4 39 Cl 57 HCO_3 1,350 T.S. 1,324 *Third Cat Creek* Na 354 Ca 0 Mg 0 SO_4 289 Cl 35 HCO_3 515 T.S. 930	Not tested	Not tested	Not tested	
SOUTH WILLOW CREEK T. 11 N.—R. 23 E.	Absent	Surface formation	*Lakota* Na 282 Ca 15 Mg Tr SO_4 136 Cl 11 HCO_3 600 T.S. 739	Absent or very thin	*"Quadrant"* Na 1,025 Ca 278 Mg 79 SO_4 2,589 Cl 162 HCO_3 395 T.S. 4,327	Not tested	

APPENDIX—*Continued*

Field and Location	Formations						*Remarks*
	Montana Group	*Colorado Shale*	*Kootenai Formation*	*Ellis Formation*	*"Quadrant" and Tensleep Sandstone*	*Madison Limestone*	
			SOUTHERN FIELDS				
LAKE BASIN T. 1 N.—R. 21 E.	Surface formation	*Frontier* Na 12,566 Ca 217 Mg 83 SO_4 0 Cl 19,240 HCO_3 1,320 T.S. 32,755	*Greybull* Na 2,381 Ca 0 Mg 0 SO_4 31 Cl 2,600 HCO_3 1,805 T.S. 5,899 *Pryor cgl.* Na 1,709 Ca 32 Mg 0 SO_4 0 Cl 2,074 HCO_3 1,050 T.S. 4,331	Not tested	Not tested *"Quadrant"* Na 364 Ca 681 Mg Tr SO_4 2,166 Cl 32 HCO_3 230 T.S. 3,356	Not tested	
HARDIN T. 1 S.—R. 33 E.	Absent	Surface formation		Not sampled		Not tested	
LAUREL T. 2 S.—R. 24 E.	Absent	*Frontier* Na 733 Ca 0 Mg 0 SO_4 0 Cl 123 HCO_3 1,750 T.S. 1,709	Not sampled	Not sampled	*Tensleep* Na 1,389 Ca 287 Mg 695 SO_4 5,539 Cl 410 HCO_3 305 T.S. 8,470	Not tested	

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LATE PALEOZOIC STRATIGRAPHY OF GORE AREA, COLORADO[1]

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ABSTRACT

The late Paleozoic sediments of the Gore area in Eagle and Summit counties, Colorado, are described as to lithology, thickness, stratigraphic relations, geologic history, and fauna. The stratigraphic names Weber and Maroon are abandoned in the area and in their place the name Battle Mountain formation is proposed[3] for the thick sequence of Pennsylvanian clastics. The term Belden shale member of the Battle Mountain formation is proposed to replace the name Weber shale in the area. The Robinson and Jacque Mountain limestones are reduced to the rank of members of the Battle Mountain unit. The manuscript name of State Bridge formation is here applied to the upper Pennsylvanian or Permian sediments which lie between the Battle Mountain formation and the Triassic.

The erstwhile Permian plant *Walchia* is found to be associated with marine invertebrate fossils of Des Moines age. At least a part of the gypsum of the Eagle Basin is shown to be of Des Moines age.

INTRODUCTION

The region spoken of as the Gore area covers approximately 350 square miles in Eagle and Summit counties, Colorado (Fig. 1). It is about 120 miles west of Denver, its southern margin being the Continental Divide 13 miles north of Leadville. The southern part of the area contains the Tenmile District which was mapped by Emmons (6).[4]

The area is accessible by means of black-top highways in the valleys of Eagle River and Tenmile Creek, and good dry-weather roads in the valleys of Turkey and Gore creeks.

The field work was done during the summer and fall of 1938 and the spring of 1939 with the view of determining the exact age, stratigraphic relations, structure, and geologic history of the upper Paleozoic rocks of the area.

Used as a base for mapping, were the United States Geological Survey topographic maps of the Minturn Quadrangle (scale 1/62,500), Mt. Powell Quadrangle (1/48,000), and Dillon Quadrangle (1/48,000), supplemented by the Tenmile District Special Folio (1/31,680) of the United States Geological Survey Atlas, and by the United States Forest Service map of the Holy Cross National Forest.

The location of points was determined by pace traverse, and by triangulation with a Brunton compass. Some elevations were obtained by reference to topographic maps and were checked by means of an aneroid barometer. Others were determined by reference to a series of United States Geological Survey bench marks in the valleys of Eagle and Piney rivers and Gore and Turkey creeks.

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[3] New names proposed have been checked with the committee on geologic names, United States Geological Survey.

[4] Figures in parentheses indicate references at end of text.

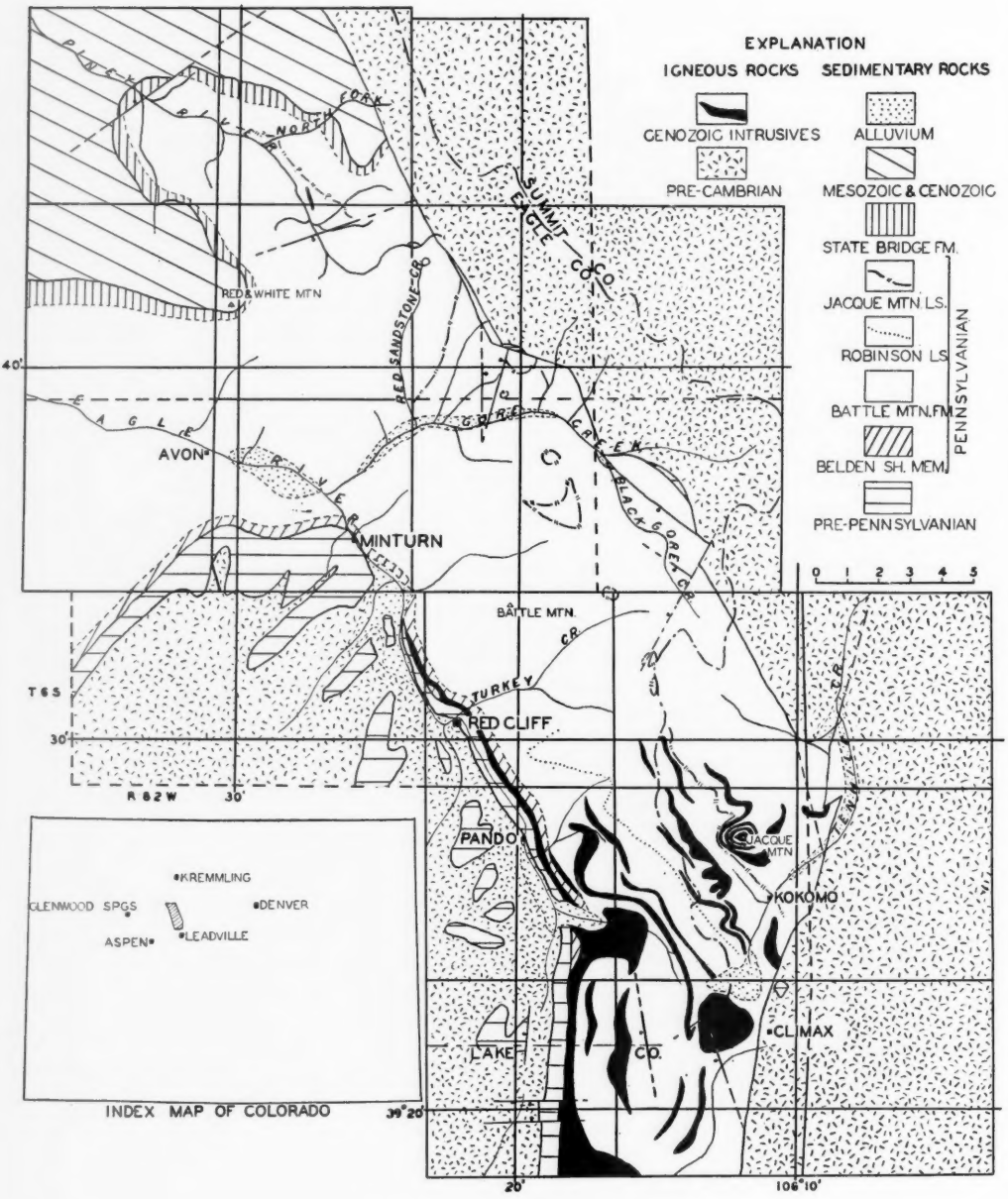

FIG. 1.—Geologic map of Gore area.

The writer is deeply indebted to T. S. Lovering and G. M. Ehlers of the University of Michigan for their suggestions and encouragement in the field and laboratory. To Carl O. Dunbar, Norman D. Newell, and A. K. Miller, the writer is grateful for their identification of some of the fossil invertebrates.To Paul D. Krynine, thanks are due for his identification of various stratigraphic minerals in the redbed samples, and also to Don B. Gould who very kindly guided the writer over the Salt Creek area. The writer wishes to thank Quentin D. Singewald for the use of field data on the Alma district.

STRATIGRAPHY

PRE-PENNSYLVANIAN SYSTEMS

The Paleozoic sediments in the region studied range from the Upper Cambrian to the Pennsylvanian or Permian. They lie in a belt 35 miles long and 10 miles wide, in the form of a broad asymmetrical syncline, the axis of which strikes N. 45° W. On the southwest side of the Gore area, the pre-Cambrian granites and gneisses form the Sawatch Range. The Paleozoic sediments dip 25° E. off the slopes of the range. Just north of the Sawatch Mountains on the northwest side of the area, the Paleozoic and Mesozoic sediments dip northwest and form the eastern edge of the Eagle Basin (Fig. 1). On the east side of the area the Gore and Mosquito faults have thrust up the pre-Cambrian against the Paleozoic and Mesozoic rocks. The drag of the fault increased the west dip of the sediments, making the east limb of the syncline shorter and steeper. The Gore and Tenmile ranges, composed of pre-Cambrian granites, bound the east side of the area.

The pre-Pennsylvanian systems present consist of the upper Cambrian Sawatch quartzite, the lower Ordovician Manitou limestone and the Mid-Ordovician Harding sandstone, the upper Devonian Chaffee formation containing two members, the Parting quartzite below and the Dyer dolomite above, and the lower Mississippian Leadville limestone resting unconformably beneath the Pennsylvanian strata.

The outcrops of these earlier Paleozoic rocks are confined almost entirely to the west side of the area along the valley of Eagle River; however, small patches of quartzite are present, resting on the granite just east of the Gore and Mosquito faults (15). Lovering and Johnson refer the quartzitic conglomerate in two outliers east of the Gore fault to the Parting quartzite. One of these outliers is near Bald Mountain (Sec. 27, T. 4 S., R. 80 W.). Another is on Miller Creek (Sec. 16, T. 5 S., R. 79 W.). Between these two patches, Pennsylvanian clastics may be seen resting on the pre-Cambrian, which indicates the lack of consistency in the presence of the pre-Pennsylvanian strata on the eastern side of the region. Little Bartlett Mountain just north of Climax is capped by quartzite which Emmons (6) referred to the Sawatch. From these indications it is clear that the Ordovician strata, the Dyer dolomite and the Leadville limestone, which are present on the west side, disappear somewhere beneath the area and are not found in the out-

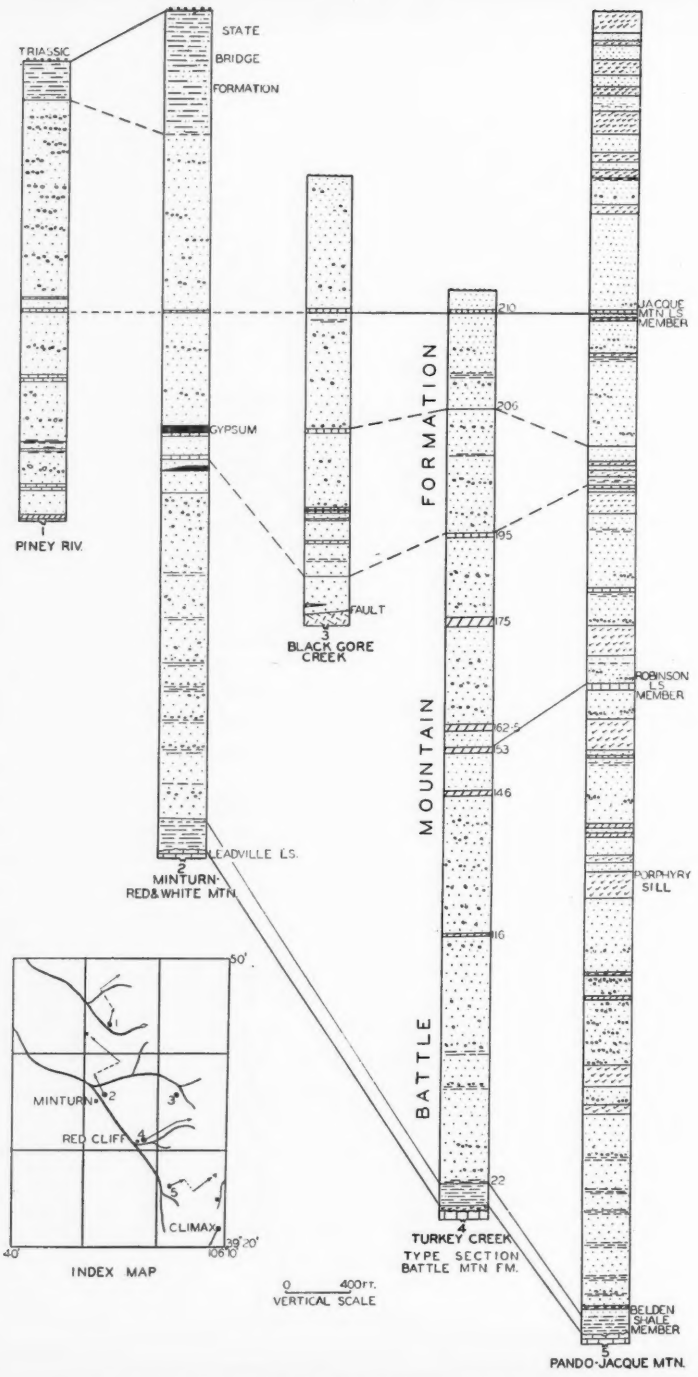

FIG. 2.—Columnar sections of late Paleozoic rocks in Gore area.

liers farther east. Whether due to non-deposition or to pre-Pennsylvanian erosion, the absence of these formations on the east has clearly established the presence of the Front Range highland as a positive area during much of the Paleozoic era.

LATE PALEOZOIC SYSTEMS

Battle Mountain formation.—The term is proposed for the sequence of lower Pennsylvanian rocks which lies uncomformably on the Mississippian and older rocks, and which is disconformably overlain by the State Bridge formation. The name is derived from Battle Mountain, 3.5 miles northeast of Red Cliff, Colorado. The type section measured on the north side of Turkey Creek is here given.

TYPE SECTION OF BATTLE MOUNTAIN FORMATION

Section begins on top of Hill 11610 (Minturn Quadrangle) west of Dagett Pass (Shrine Pass road) about 6 miles east of Red Cliff, Eagle County, Colorado.

Pennsylvanian: Battle Mountain formation

Interval Number		*Thickness in Feet*
213	Sandstone micaceous, red, thin-bedded, cross-bedded	64
212	Limestone crystalline, dark gray, weathers light gray	2.5
211	Sandstone micaceous, light red, calcareous at base	66
	Jacque Mountain limestone member (interval 210)	
210	Limestone oölitic, light gray with purplish cast in some beds, some beds of breccia. Contains: *Schizodus* sp. *Bellerophon* cf. *B. crassa*	18
	Offset west along ridge to outcrops in cirque. Interval along ridge is covered	
209	Covered. Probably the same material as interval 208	300
208	Sandstone and grit arkosic, conglomeratic with pebbles of igneous rocks up to 3 inches in diameter near top of interval, dark red mottled with gray, cross-bedded, ripple-marked, sun-cracked. Nodular purple limestone about 2 feet thick near middle of interval	220
207	Sandstone and grit light gray to pinkish gray	50
206	Limestone finely crystalline, dark gray, with crinoid columnals, small gastropods recrystallized	2
205	Sandstone arkosic, dark red mottled with gray, thin-bedded, cross-bedded; some grit and a conglomerate with limestone pebbles are present. Interval covered in places	170
204	Sandstone and shale interbedded, micaceous; sandstone fine-grained; shale sandy, contains: *Mesolobus mesolobus, Chonetina* cf. *C. flemingi, Spirifer* n. sp., *Composita* (?) sp.	6
	Offset about ¼ mile west	
203	Sandstone micaceous, brownish gray, cross-bedded, beds 0.5 to 1 foot thick. Some beds weather reddish brown. Contains plant remains in some places	25
202	Covered. Sandstone and grit gray to pinkish gray in float	150
201	Grit arkosic, fine-grained, light gray	4
200	Covered. Gray grit and sandstone in float	200
199	Sandstone micaceous, light brownish gray, weathers brown, with abundant limonite on weathered outcrop	4
198	Covered. Float seems to indicate light gray sandstone and grit, with some red	100
197	Limestone crystalline, light gray, weathers purplish gray. Contains: brachiopods and gastropods. Perhaps fusulines in float belong to this bed	5
196	Covered. Perhaps light gray sandstone with some limestone	130
195	Limestone finely crystalline, medium gray; lower 10 feet massive with fragments of white quartz ⅜ inch in diameter; above this the beds are 2 inches thick, with several beds of breccia, other beds contains *Composita subtilita;* upper 12 feet dark gray and top one foot has dolomitic patches and contains *Neospirifer* sp. Scour-and-fill structure near top. Contains: *Dictyoclostus* cf. *D. portlockianus, Marginifera muricatina, Spirifer* cf. *S. opimus, Ambocoelia planoconvexa*	25
194	Covered. Probably arkosic, greenish gray conglomerate in lower 50 feet; and light brown sandstone in upper	147

Interval Number		*Thickness in Feet*
193	Limestone crystalline, light gray, thin irregular beds of sand grains	6
192	Covered	42
191	Limestone dark gray	10
	Offset 200 yards west to slope of hill	
190	Covered. Probably micaceous, gray sandstone	92
189	Limestone crystalline, dark gray, weathers bluish gray, somewhat dolomitic	1
188	Sandstone micaceous, gray	6
187	Limestone dark gray, weathers bluish gray, with patches of dolomite, weathers brown (more dolomite than in interval 189). Contains: recrystallized crinoid columnals and brachiopods	5
186	Covered	25
185	Grit arkosic, conglomeratic with pebbles 2 inches in diameter, gray	6
184	Dolomite crystalline, gray, weathers brown	2
183	Limestone dark gray, irregular contact with interval 182; contains inclusions of interval 182	3
182	Dolomite crystalline, gray, weathers brown	3
181	Sandstone micaceous, gray, cross-bedded, thickens southeast and grades laterally into arkosic, pinkish gray grit	7
180	Covered	25
179	Grit and sandstone arkosic, micaceous, greenish gray, cross-bedded. Looks like an unconformity above it	48
178	Covered	15
177	Sandstone micaceous, light gray, cross-bedded, thin-bedded	30
	Offset ¼ mile west along hillside	
176	Sandstone micaceous, brownish gray, weathers light brown; slabby with paper shale partings in lower 20 feet, grading upward into calcareous gray grit with limestone pebbles	25
175	Dolomite crystalline, gray, weathers brown, more calcareous toward base	50
	Offset about 1 mile southwest along hillside	
174	Covered. Probably gray sandstone	30
173	Grit conglomeratic, light gray	10
172	Covered	126
171	Sandstone micaceous, gray, thin-bedded	12
170	Grit micaceous, conglomeratic pebbles up to 8 inches in diameter, light gray	96
169	Sandstone conglomeratic, a few large pebbles of igneous rocks, light gray, cross-bedded, thin-bedded. Finer than interval 170	162
168	Covered	25
167	Sandstone light gray, thin-bedded, cross-bedded	15
166	Covered	47
165	Shale dark gray to black, with dolomite beds up to 1 foot thick	18
164	Limestone breccia with a few angular grains of quartz	2
163	Shale dark gray to black, with gray dolomite beds up to 1 foot thick. Shale contains: worm trails, *Patellostium montfortianum*, *Trepospira depressa*, other gastropods	6
162	Dolomite very gritty, almost conglomerate with pebbles of quartz and igneous rocks and cobbles of gray dolomite, flakes of mica; gray	28
161	Grit arkosic, conglomeratic with scattered pebbles, micaceous, non-calcareous, greenish gray, cross-bedded, lower 14 feet finer-grained	35
160	Covered	13
159	Shale micaceous, arenaceous, black	3
158	Dolomite light gray, weathers buff, thin-bedded, almost cross-bedded in upper part, very lumpy and irregular	26
157	Sandstone micaceous, gray	6
156	Sandstone micaceous, red	2
155	Grit arkosic, conglomeratic, greenish gray to gray, cross-bedded	25
154	Dolomite massive, dark gray, weathers brown and rough	7
	Robinson limestone member (interval 153)	
153	Dolomite dark gray to black, thin-bedded, nodular with black shale partings, calcareous at base. Contains: corals, *Marginifera* cf. *M. lasallensis*, *Ambocoelia ?* sp.	15
152	Dolomite light gray, nodular, sandy at top	8
151	Sandstone greenish gray, cross-bedded, shaly near the base	10
150	Covered. Some gray sandstone, grit gray, cross-bedded, 10 feet thick, 128 feet above base of interval	200

Interval Number		*Thickness in Feet*
149	Shale micaceous, dark gray	4
148	Sandstone micaceous, dark gray, thin-bedded	2
147	Shale micaceous, arenaceous, dark gray	18
	Offset 1.5 miles west on heavy dolomite bed	
146	Dolomite medium gray, weathers brown, massive, thin-bedded at top; with gray chert nodules. Cliff-former	30
145	Grit arkosic, greenish gray, highly cross-bedded, with beds of sandstone and conglomerate	56
144	Sandstone micaceous, dark gray	1
143	Shale dark gray	2
142	Dolomite light gray, weathers buff, sandy, irregularly bedded	12
141	Covered. Perhaps gray grit and sandstone	78
140	Shale dark gray, with dolomite nodules and worm (?) tracks	12
139	Dolomite dark gray, weathers brown	7
138	Covered. Probably same as interval 137	12
137	Grit conglomeratic, greenish gray	12
136	Dolomite dark gray; breaks into slabs 2 inches thick	7
135	Sandstone light gray	2
134	Covered	40
133	Shale micaceous, very arenaceous, breaks into large slabs, dark greenish gray	22
132	Grit light gray, cross-bedded at base	3
131	Dolomite dark gray, weathers brown, breaks into slabs 2–3 inches thick; some beds have greenish gray sand mixed with dolomite	13
130	Grit, light gray, massive, calcareous cement	15
129	Dolomite dark gray, weathers brown	8
128	Sandstone micaceous, very thin-bedded, shaly, non-resistant	6
127	Grit with some sandstone, light gray	4
126	Dolomite dark gray, weathers brown, many fragments of quartz, contact with interval 125 gradational	4
125	Grit conglomeratic, quartzitic, light gray	6
124	Shale micaceous, very sandy, dark gray, cross-bedded	4
123	Shale micaceous, gray to brownish gray, thin-bedded; interbedded with dark gray shale	54
122	Covered. Large blocks of grit in lower 15 feet	50
121	Dolomite dark gray, weathers brown, many grit fragments of quartz	5
120	Grit and sandstone, gray, very irregularly bedded, cross-bedded	10
119	Grit arkosic, conglomeratic, light gray, sandy at top and overlain by 3 feet of gray shale	15
118	Sandstone micaceous, conglomeratic, with small pebbles of quartz and igneous rocks, greenish gray, cross-bedded, weathers thin-bedded	50
117	Covered. Grassy slope	320
	Section ends on north side of Turkey Creek at mouth of Wearyman Creek, at top of cliff. Offset on dolomite bed to west side of Lime Creek	
116	Dolomite crystalline, dark gray, weathers brown, lower 2 feet gritty; becomes sandy in places along trace	10
115	Grit and sandstone with black shale beds; light gray thin-bedded, cross-bedded. Contains plant remains	96
114	Dolomite crystalline, gray, weathers brown, with black chert nodules containing white, high-spired gastropods	7
113	Grit very conglomeratic with rounded pebbles of quartz; medium gray	20
112	Sandstone and grit with some shale; light gray to greenish gray; grit conglomeratic; shale micaceous, thin beds, gray "cake-frosting" markings on bedding planes	200
111	Sandstone and shale alternating beds; sandstone micaceous dark red; shale greenish gray and dark red. Some conglomerate in upper part of interval, becomes light gray laterally toward east in places	60
110	Sandstone and grit, light brownish gray, partly covered	30
109	Grit arkosic, conglomeratic with pebbles of quartz and igneous rocks, calcareous cement, pink, grades upward into cross-bedded sandstone and dark red shale	12
108	Grit conglomeratic with pebbles of rounded quartz, cross-bedded; sandstone beds; light gray becoming pink 8 feet above base of interval and dark red 14 feet above base; much micaceous, dark red shale and some greenish gray shale in upper part of interval	90
107	Sandstone micaceous, greenish gray, ripple marks, with thin shale on top	2

Interval Number		*Thickness in Feet*
106	Shale micaceous, arenaceous, light gray	3
105	Sandstone micaceous, light gray, thick-bedded	5
104	Grit conglomeratic, dark red	8
103	Shale greenish gray to dark red, with some sandstone lenses	4
102	Grit arkosic, conglomeratic pebbles of chlorite schist and other rocks, purplish red to gray, finer-grained and cross-bedded at top. Grades into shale	12
101	Sandstone micaceous, red and gray with some red shale Section ends in small draw 100 feet west of mouth of Lime Creek about 150 feet above road. Offset about 0.5 mile west following bedding.	15
100	Sandstone and shale interbedded; mainly sandstone, gray to dark red	20
99	Shale red and green	2
98	Sandstone dark red, cross-bedded	6
97	Shale red and green	2
96	Grit gray	4
95	Shale greenish gray pinches out laterally	2
94	Grit conglomeratic, red	12
93	Shale greenish gray and dark red	3
92	Grit and sandstone conglomeratic, light gray, cross-bedded, becomes red laterally in places	20
91	Sandstone dark red with beds of dark red shale	34
90	Grit conglomeratic, dark red, cross-bedded	25
89	Covered	12
88	Grit conglomeratic with sporadic pebbles or streaks of pebbles, dark red, cross-bedded	20
87	Covered. Probably red sandstone and grit	30
86	Shale, greenish gray in float	13
85	Grit conglomeratic, pinkish gray	6
84	Covered. Probably red sandstone, grit, and shale	30
83	Shale micaceous, dark red and pinkish buff	6
82	Sandstone dark red, cross-bedded, some thin shale	24
81	Shale dark red	3
80	Sandstone dark red, cross-bedded, a little grit at base	15
79	Shale dark red	6
78	Grit conglomeratic, dark red	5
77	Shale dark red	3
76	Grit conglomeratic with rounded pebbles of quartz up to 3 inches in diameter; dark red. Grades upward into cross-bedded, red sandstone	15
75	Shale dark red with thin beds of sandstone	10
74	Grit conglomeratic pebbles of quartz, calcareous cement; becomes gray and more sandy toward top	16
73	Shale and sandstone alternating beds, dark red	5
72	Grit conglomeratic, dark red	13
71	Shale dark gray with some greenish gray bands. Contains buff bentonite, 3 inches thick	3
70	Grit dark red with some interbedded shale	10
69	Grit conglomeratic, pinkish gray, with sandstone, dark red and cross-bedded at top	9
68	Shale dark red	2
67	Sandstone dark red	8
66	Grit conglomeratic, pinkish gray, more gray than intervals below. Rests with irregular contact on interval 65	10
65	Grit and sandstone interbedded, with some red shale; dark red; grit conglomeratic, partly covered	66
64	Shale red	18
63	Grit, a few quartz pebbles, dark red	6
62	Shale red partly covered	20
61	Shale greenish gray, with thin sandstone beds	6
60	Covered. Perhaps red shale	3
59	Grit irregular contact with sandstone of interval 58; conglomeratic, much chlorite schist, pink to dark red; upper 3 feet sandstone, dark red. Jointing that looks like cross-bedding	10
58	Grit conglomeratic, cross-bedded, pinkish gray, with red sandstone at top. Some shale in upper part of sandstone. Cyclothem	12

Interval Number		*Thickness in Feet*
57	Shale micaceous, red and greenish gray	2
56	Grit pink to red, with interbedded cross-bedded red sandstone, and red shale; gradational contact with interval 55	40
55	Grit conglomeratic, with many pebbles of chlorite schist, light gray, cross-bedded	5
54	Shale micaceous, dark red	2
53	Covered	6
52	Grit conglomeratic, greenish gray, grades up into shale at top	12
51	Shale micaceous greenish gray, with beds of light gray sandstone	3
50	Shale micaceous, carbonaceous, black	1
49	Grit conglomeratic, pebbles of quartz, gray to greenish gray; becomes pink along trace westward	50
	Section ends at abandoned adit about 300 feet east of mouth of Kiln Creek. Offset to hillside just west of mouth of Kiln Creek on north side of Turkey Creek	
48	Covered	40
47	Sandstone micaceous, light gray, cross-bedded	6
46	Covered	10
45	Shale micaceous, arenaceous, red and green	6
44	Grit conglomeratic, with pebbles of quartz, light gray	6
43	Sandstone light gray, weathers brown; marbled appearance	3
42	Covered	8
41	Grit arkosic, conglomeratic, with pebbles of quartz, interbedded red and green shale; purplish pink	30
40	Sandstone purplish red. Partly covered	12
39	Shale greenish gray	1
38	Grit conglomeratic with pebbles of quartz, light gray	40
37	Shale micaceous, greenish gray to dark gray, with calcareous gray sandstone	4
36	Grit with layers of white quartz pebbles, cross-bedded, hard	12
35	Shale greenish gray	2
34	Grit dark greenish gray	4
33	Shale dark gray and greenish gray, thin gray limestone	3
32	Grit with streaks of pebbles, light gray, weathers tan, thin-bedded, cross-bedded	11
31	Grit light gray, weathers white, softer than interval 32	8
30	Covered. Black shale at base	12
29	Sandstone quartzitic, pinkish white	7
28	Covered. Muddy dolomitic limestone in interval	12
27	Grit quartzitic, cross-bedded, pinkish gray	18
26	Shale dark gray, some muddy limestone	12
25	Sandstone quartzitic, small glassy quartz fragments	3
24	Covered	5
23	Grit quartz fragments, limonite, light gray	9
	Belden shale member (interval 1–22)	
22	Covered. Probably dark shale	26
21	Grit with quartz fragments and limonite, light gray. Some thin gray shale	11
20	Shale black to dark gray, calcareous	7
19	Sandstone micaceous, fine-grained gray	1.5
18	Shale black with gray limestone. Partly covered	5
17	Sandstone light gray, quartzitic	2
16	Shale greenish gray to dark gray	4
15	Sandstone calcareous, dark gray	0.5
14	Shale gray	3
13	Sandstone light gray, weathers white with brown streaks	1
12	Shale gray, with nodules of impure limestone	2
11	Sandstone micaceous, light gray, weathers brownish gray	4
10	Shale dark gray	2
9	Limestone muddy, dark gray to black	3.5
8	Covered. Probably dark gray shale	3
7	Sandstone calcareous, dark gray	0.5
6	Limestone muddy, dark gray	2
5	Limestone and shale dark gray	20
4	Sandstone light gray weathers brown	2

Interval Number		*Thickness in Feet*
3	Shale micaceous, light gray	4
2	Sandstone micaceous, dark gray	3
1	Covered. Probably black shale	20
	Porphyry sill at base of Pennsylvanian	

Leadville limestone

Section ends about 200 feet east of Liberty Mine 0.2 mile east of Red Cliff, Eagle County, Colorado

The Battle Mountain formation is about 4,300 feet thick in the north part of the area and more than 7,900 feet in thickness farther south. (Nearly 1,600 feet are porphyry sills of Cenozoic age.) It is composed mainly of grits and sandstones, but also contains thick beds of shale and conglomerate. Here and there beds of limestone and dolomite are present which range from a few inches to 30 feet in thickness.

In earlier reports (3, 6, 11), the sequence of sediments here assigned to the Battle Mountain formation was divided into six formations on the basis of lithology or color. From the oldest to youngest these were the Weber formation (divided into the Weber shale and Weber grit), Robinson limestone, White Quail limestone, Maroon formation, Jacque Mountain limestone, and Wyoming formation.

The name Weber, proposed by King (12), was first used in the Gore area by Emmons (6) who correlated the lower Pennsylvanian with that of the type locality in Weber Canyon, Utah.[5] Emmons (6) considered the Weber shale to be transitional between the underlying Leadville limestone and the overlying Weber grits. The contact between the shale and grit is gradational and the thickness and character vary locally. In this paper the name Belden shale member is proposed to replace the name Weber shale. The term Maroon formation, applied by Emmons to the red beds above the Weber was adopted from the Crested Butte district. The Weber grit was separated from the Maroon formation by about 30 feet of carbonate rock called the Robinson limestone, named from the then active Robinson Mines north of Climax, Colorado (6). The separation of the clastic beds above and below the Robinson limestone was made by Emmons chiefly on the criterion that the non-clastic beds in the Weber grit were dolomite, and that those above in the Maroon formation were limestone. Although this distribution of carbonate beds holds true in a general way, detailed work has shown that thin dolomites occur above the Robinson and there are a few limestones below it. Furthermore the Robinson itself varies from limestone to dolomite in a few miles along the strike. Although it loses its identity before the latitude of the town of Red Cliff is reached, it is useful as a horizon marker in the south part of the area and is therefore made a member of the Battle Mountain formation. The red color of the Maroon formation has been regarded as significant in separating it from the Weber. The present writer has observed that

[5] The accuracy of this correlation was in question as early as 1903 (7, p. 171).

the color crosses the bedding planes obliquely, and that the base of the red color zone, which is found at the top of the Robinson limestone member in the south part of the area, is stratigraphically higher farther north. Furthermore, there is no faunal difference between the upper Weber shale, Weber grit, and a large part of the Maroon formation. For these reasons, the present writer believes that the terms Weber and Maroon should be abandoned in the Gore area.

The White Quail limestone which Emmons named for the Quail Mines has a very limited extent and although it may be useful in the Tenmile district in subsurface work, it is not considered in this paper as a horizon marker.

The Jacque Mountain limestone, composed of 30 feet of oölitic limestone, was named by Emmons (6) for Jacque Mountain just northwest of Kokomo, Colorado, and originally separated the Maroon formation from the Wyoming formation. The term Wyoming was introduced by Emmons (6) from eastern Colorado. This stratigraphic name was subsequently abandoned and the term Maroon formation extended above the Jacque Mountain limestone to include all of these upper redbeds (11). The Jacque Mountain limestone is an excellent horizon marker and can be traced northward more than 20 miles from the type locality. Because of its value in mapping it is here given the rank of member of the Battle Mountain formation.

Belden shale member.—The name Belden shale member of the Battle Mountain formation is proposed for the lower Pennsylvanian strata in this area which heretofore have been designated the Weber shale. The name is derived from the station of Belden on the Denver and Rio Grande Western Railroad, Eagle County, Colorado.

TYPE SECTION OF BELDEN SHALE MEMBER

Section measured on north side of Rock Creek valley along U. S. Highway 24 (1938) 0.2 mile north of Gilman, Colorado

Pennsylvanian: Battle Mountain formation

Interval Number		*Thickness in Feet*
	Belden shale member	
31	Covered. Lower 30 feet has gray shale and dark gray limestone. Limestone contains: *Paeckelmannia* sp., *Chonetes* sp., *Chonetes* cf. *C. granulifera*, *Squamularia* n.sp., *Composita subtilita;* shale contains fossil wood	150
30	Limestone finely crystalline, dark gray to black, with thin shale partings	2.5
29	Shale laminated, gray	10
28	Limestone and shale interbedded; limestone finely crystalline, dark gray, beds less than 1 foot thick; shale gray	4.5
27	Shale laminated, dark gray	1
26	Limestone dark gray, fractures into angular blocks; a few thin shale beds near base	4
25	Shale laminated at base, calcareous and more resistant above, gray	2
24	Limestone finely crystalline, dark gray, weathers brown	2
23	Shale laminated, dull gray	2
22	Limestone like interval 24	2
21	Shale like interval 23	2
20	Limestone dark gray, with red shale in bedding planes	1.5
19	Coal very impure	1
18	Shale fissile, black, interbedded with thin calcareous beds. Lower part gypsiferous	10
17	Limestone very argillaceous, soft, fractures into angular blocks, greenish gray, weathers tan	2

Interval Number		*Thickness in Feet*
16	Shale fissile, black with beds of black limestone, weathers brown	4
15	Limestone finely crystalline, wavy bedding planes, black. Thickens and thins as if erosion had scoured surface	2.5
14	Shale laminated, dark gray, with interbedded dark gray limestone, which has blocky fracture	3
13	Covered. Perhaps gray shale	10
12	Limestone finely crystalline, dark gray, weathers brown	1
11	Shale laminated, with nodules of limestone, gray, weathers brown	1
10	Limestone, gray, weathers brown	0.5
9	Shale calcareous, irregularly bedded, gray, weathers yellowish brown	4
8	Shale fissile, black at base, dark gray above, weathers yellowish brown	2
7	Limestone crystalline, dark gray, calcite veinlets	1
6	Covered	7
5	Limestone argillaceous, dark gray	0.8
4	Covered (old road)	6
3	Shale light gray at base black above. Lower part baked by sill	3
2	Porphyry sill	30
1	Shale dark gray to black, weathers yellowish brown in spots, perhaps some thin coal lenses. Can be best observed underground in Eagle Mines	10
	Unconformable contact with Leadville limestone	

The foregoing type section is exposed along U. S. Highway 24 on the north side of Rock Creek across the valley from the town of Gilman. Here the member is more than 125 feet thick. The Belden shale rests unconformably on the Leadville limestone and is composed of 100–200 feet of black and dark gray, carbonaceous shale, and argillaceous limestone with thin beds of dark-colored sandstone. Very thin seams of impure coal are present in some localities. On the eastern side of Eagle River between Red Cliff and Pando, the Belden shale is about 200 feet thick. Farther south it appears sporadically but is much disturbed by Cenozoic intrusives, and is therefore difficult to follow. On the east side of Tennessee Pass in the south end of the area, it seems to be at least 300 feet thick, but is not well exposed. North of the type section in the vicinity of Minturn, there are about 200 feet of shale, largely covered, however. West of Minturn the shales are found on the dip slopes on the north and east sides of the Sawatch Range. There it is difficult to determine the thickness because the shales erode readily. Although the basal contact with the Mississippian limestone is not well exposed because of the non-resistant character of the shale, it is irregular, because of erosion of the underlying beds. The unconformable contact has been observed in the workings of the Eagle Mines, Gilman, Colorado.[6] The contact with the overlying undifferentiated Battle Mountain formation is gradational, the shales giving way to beds of light-colored sandstone and grit which increase in thickness as the shales decrease. The present writer has drawn the upper limit of the Belden where the shales and dark sandstones cease to predominate in the section.

In the outliers to the east of the area, the coarse clastics rest on granite and there is nothing which corresponds to the Belden shale member. In a large slice of Pennsylvanian sediment carried upward along the Gore fault (Fig. 1, Secs. 17, 21, 28, T. 4 S., R. 80 W.) there are fossiliferous black shales. Their fauna

[6] Oral communication, Dr. Horatio Brown, Gilman, Colorado, August, 1938.

is composed of fusulinids and other elements which are Des Moines in age, but different from the typical Belden shale member of the western side of the area. The base of the Pennsylvanian section is not exposed in the north end of the area along Piney River.

The presence of black, carbonaceous shale and local coal seams which contain fossil plants belonging to the Lycopodiae suggests a paludal environment. Interbedded argillaceous limestones contain in some places a marine invertebrate fauna which is distinctive from that of the overlying strata. *Orbiculoidea* cf. *C. capuliformis*, *Derbya* sp., *Paeckelmannia* n. sp. (more flattened umbo and somewhat smaller than *P. derelicta*), *Chonetes* sp. (small flat and plicate), *Chonetes* cf. *C. granulifera*, *Squamularia* n. sp., *Composita subtilita*, and poorly preserved pelecypods comprise the fauna. This assemblage has been found at the type locality and several miles farther south in the vicinity of Red Cliff. It has not been found as far north as Minturn or as far south as Pando.

A species of *Paeckelmannia* has been described from the Smithwick of Texas by King (13), and heretofore this occurrence was unique in North America. Although it is found in the pre-Des Moines strata of Texas, *Paeckelmannia* seems to range up into the Des Moines in Colorado. It is not associated with diagnostic fossils in the Gore area, but in the vicinity of Dotsero and Glenwood Springs farther west it is found in the equivalent of the Belden member with a typical Des Moines fauna.

As may be noted on the columnar sections (Fig. 2) the thickest section of the Battle Mountain formation is present at the south end of the area. In columnar section 5, 6,300 feet of sediment (not including sills) have been measured. An unknown amount has been eroded off the top. In the north part of the area, in columnar section 2, the formation is about 4,300 feet in thickness; however, the thickness may be about 100 feet less because of repetition of the beds by faulting between Gore Creek and Red and White Mountain.

The lower 500 feet of the Battle Mountain formation which lies above the Belden member contains much coarse clastic material in the central part of the area. This interfingers with gray and greenish gray shales north of Minturn and south of Red Cliff. Thus, in these parts of the area, the finer sediment occurs much higher in the section.

The bulk of the sediment between the Belden shale and Jacque Mountain limestone is sandstone and grit. These commonly contain fragments of mica and potash feldspar as well as quartz. In the conglomerates are pebbles of quartz, metamorphic and acid igneous rocks, as well as a few pebbles of limestone all of which are rounded or sub-angular. Some of these are as much as 6 inches in diameter. Cross-bedding, scour-and-fill structures, rill marks, and ripple marks are very common. Mud lumps and desiccation fissures are present in many of the shale beds. The color in the lower part is buff-gray, greenish gray, salmon-pink or dark red; in the upper part it is dark red or brilliant red. Well defined cyclothems are

noticeable. A typical cycle consists of: (1) thick, massive conglomeratic grit, resting on the stratum below with an irregular contact; (2) thin-bedded sandstone above and gradational with No. 1; and (3) thin shale above and gradational with No. 2. Such cyclothems are exposed well in the cliffs on the east side of Eagle River just north of Minturn, and on the north bank of Turkey Creek, 0.7 of a mile east of Red Cliff. Examples of these may be seen in the type section of the Battle Mountain formation, intervals 66, 67, 68 and intervals 104, 105, 106.

About 950 feet above the base of the formation, a 3-inch layer of altered bentonite, containing some quartz and biotite as well as shards, has been recognized in two localities 7 miles apart. This seems to represent the eastern limit of Pennsylvanian volcanism in the United States. The location of the volcanoes which furnished the ash is not known. Detailed work on equivalent strata farther west should indicate whether this material is to be associated with the Pennsylvanian volcanism which centered in California, or whether the ash was locally derived.

About 30 feet above the top of the Belden shale member at the mouth of Game Creek at Minturn, a few rather poorly preserved fossils are present in a gray shale bed. These are: *Chonetes* sp., *Dictyoclostus portlockianus*, *Marginifera muricatina*, *Spirifer* sp. Between this horizon and the Robinson limestone member no well preserved fossils have been found. In the beds of carbonate rock and calcareous shale between the Robinson member and interval 206 of the type section (that is, between 2,720 and 4,790 feet above the base of the Pennsylvanian) the following fauna of fossil invertebrates has been found in various localities: *Fusulina* n. sp., *Lophophyllum* cf. *L. profundum*, *Campophyllum torquium*, *Chaetetes milliporaceus*, *Schizophoria* sp., *Derbya* sp., *Meekella striatocostata*, *Chonetina* cf. *C. flemingi*, *Mesolobus mesolobus*, *Dictyoclostus portlockianus*, *Dictyoclostus inflatus coloradoensis*, *Marginifera muricatina*, *Marginifera* cf. *M. lasallensis*, *Linoproductus prattenianus*, *Dielasma bovidens*, *Spirifer rockymontanus*, *Spirifer* cf. *S. opimus*, *Spirifer* n. sp., *Neospirifer* sp., *Ambocoelia planoconvexa*, *Hustedia* cf. *H. mormoni*, *Composita subtilita*, *Patellostium montfortianum*, *Trepospira depressa*, *Paraparchites* 3 n. sp., *Bythocypres pediformis*, *Ardmorea fibberosa*, *Bairdia pompiloides*, *Bairdia altiformis*(?), *Bairdia* 2 n. sp. The last six forms, which are ostracods, were identified by Miss Bertha Hecht of Columbia University. Miss Hecht states[7] that these are of Marmaton age, or at least belong in the lower half of the Pennsylvanian. These ostracods are found in the equivalent of interval 206 about 2 miles north of Turkey Creek. The faunal evidence seems to indicate clearly that this much of the Battle Mountain formation may be referred to the Des Moines series.

The next fossiliferous horizon above interval 206 is the Jacque Mountain limestone member (interval 210, type section). This contains imperfect specimens of *Myalina* sp., *Schizodus* sp., *Bellerophon* cf. *B. crassa*, *Ephippioceras* sp. The nautiloid cephalopods were examined by A. K. Miller, but because of their long stratigraphic range, he was not able to state whether they were Pennsylvanian or Permian in age.

[7] Written communication, February 25, 1939.

The Jacque Mountain limestone member is easily recognized by the fact that it is oölitic and is a prominent cliff-former maintaining a thickness of about 30 feet. It may be traced with ease from Kokomo northward to the interstream divide just east of Red Sandstone Creek. West of this divide it thins and disappears. On the north it dips beneath the overlying redbeds, but reappears in the valley of Piney River (Fig. 2, sec. 1) as 30 feet of massive limestone. The correlation of the Jacque Mountain member in columnar section 2 (Fig. 2) and in columnar section 1, is doubtful. This was made largely on the basis of stratigraphic position, color, and lithology. The oölites and the fossils, which are characteristic of this member elsewhere, are wanting. Locally the Jacque Mountain member splits into two limestone beds 100 feet apart. A structure-contour map (Fig. 3) has been drawn on the top of this member.

The portion of the Battle Mountain formation that lies between the Jacque Mountain member and the State Bridge formation is nearly devoid of fossils. The color of the clastics in this sequence is brilliant red. Lithologically it is composed of siltsone, shale, and arkosic sandstone in the southern part of the area. Along Piney River in the north part of the area it is made up of siltstones, sandstone, grits, and conglomerates. Very thin pure limestones are present in this sequence throughout the area. On Copper Mountain, 3.5 miles north of Kokomo, several hundred feet above the carbonate bed which Emmons has mapped as Jacque Mountain limestone, the present writer found specimens of fusulinids, the exterior of which is not unlike certain Pennsylvanian forms. Inasmuch as silicification had removed the internal structure, their exact age could not be determined. Although the age of this upper part of the Battle Mountain formation has not been accurately determined, and, though it could be assigned questionably to either the Pennsylvanian or the Permian system, the writer includes it in the former system. This is done on the basis of lithologic similarity and conformity with the underlying strata.

Macerated remains of the coniferous plant *Walchia* are found in a sandstone bed about 2,100 feet above the base of the Battle Mountain formation in the valley of Eagle River about one mile north of the mouth of Gore Creek. Stratigraphically higher in an undisturbed sequence, *Fusulina* sp., *Marginifera muricatina*, *Linoproductus prattenianus*, *Dielasma bovidens*, *Ambocoelia planoconvexa*, and *Hustedia* cf. *H. mormoni* are found. The guide fossil *Marginifera muricatina* indicates that these beds are Des Moines in age. The other forms are found throughout the Pennsylvanian (5). Donner, working in the McCoy area (4) first showed that *Walchia*, as well as several other genera, which have long been considered as diagnostic of the Permian system, occurred low in the Des Moines series. The presence of this form in the Missouri series of Kansas has been noted (17). It is believed to have followed a dry-soil facies rather than any particular horizon.

Aside from the red color of much of the sediment and the dry-soil character of a part of the flora, evidence of a dry climate is indicated by the presence of much anhydrite and gypsum in the Eagle Basin which adjoins the Gore area on the west. In the basin, the contorted gypsum beds are of unknown thickness and

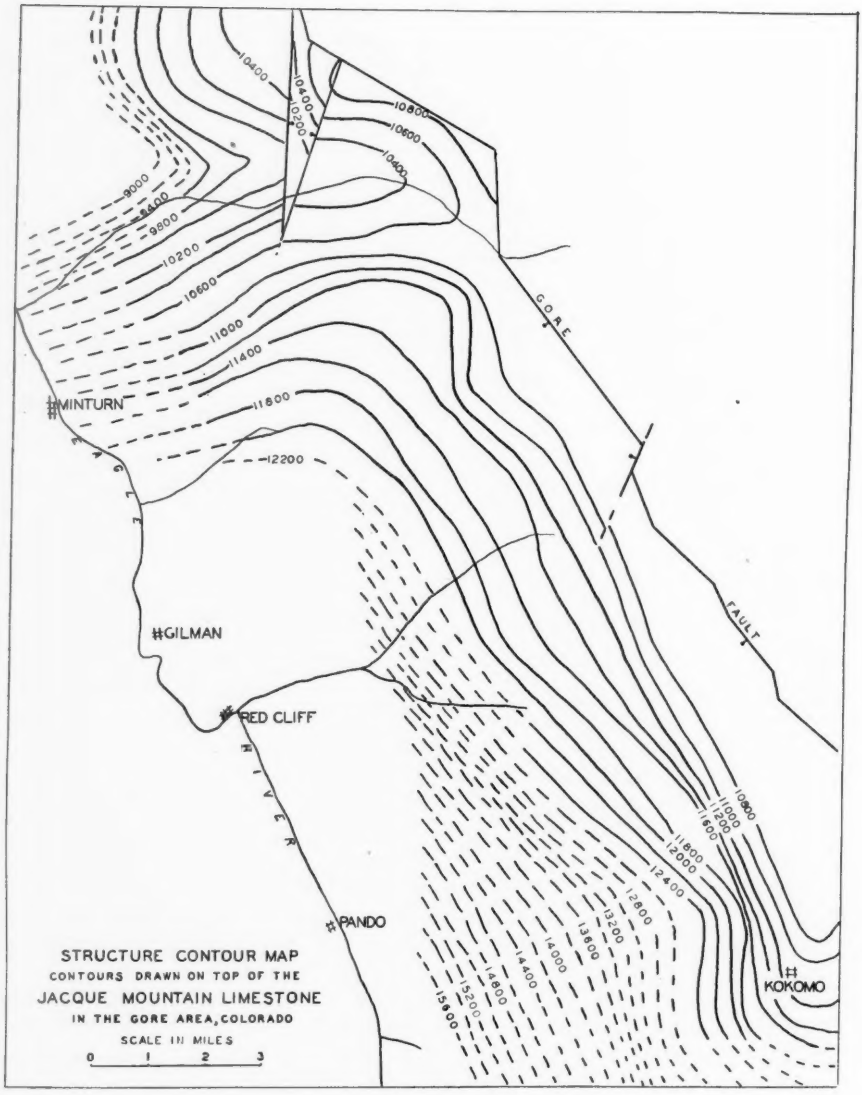

FIG. 3.—Structure-contour map of part of Gore area. Contours drawn on top of Jacque Mountain limestone.

cover several hundred square miles in the valleys of the Colorado, Eagle, and Frying Pan rivers.

About one mile north of the mouth of Gore Creek in the valley of Eagle River, 2,311 feet above the base of the Battle Mountain formation, there is a 20-foot bed of gypsum, and 200 feet stratigraphically higher, another bed of gypsum is present. These are the only beds of evaporite that are known in the Gore area and seem to represent the eastern extremity of the Eagle gypsum basin, where the beds of evaporite lense out and intertongue with the clastics of the Battle Mountain formation. Between these two gypsum beds there are limestones containing the following fossils: *Fusulina* sp., *Lophophyllum* cf. *L. profundum*, *Campophyllum* sp., *Schizophoria* sp., *Dictyoclostus* sp., *Linoproductus prattenianus*, *Marginifera muricatina* (abundant as far west as Avon), *Dielasma bovidens*, *Ambocoelia planoconvexa*, *Hustedia* cf. *H. mormoni*, *Composita subtilita*. This assemblage of fossils indicates that at least some of the gypsum is Des Moines in age. Although most of the earlier workers in central Colorado have assigned the Eagle Basin evaporites questionably to the Permian, the first worker in the region, Marvine, suggested in 1876 (18) that the gypsum extended down into the Carboniferous, north of the Eagle River.

The character of the sediment of much of the Battle Mountain formation which contains many sub-angular pebbles and fragments of feldspar, indicates that the source of material was not far away. Presumably it came from the Front Range unit of the Ancestral Rockies at the northeast and east. The mountains apparently stood high during early Pennsylvanian time and large deltas formed along the western margin near sea-level. This condition gave rise to many cross-bedded sandstones and conglomerates with interbedded marine limestone and shale. The shifting of the stream channels caused local erosional unconformities.

There are numerous sections of upper Paleozoic rocks in western Colorado which are correlative in part at least, with the Battle Mountain formation. The McCoy formation (19) on the north is lithologically very similar to the Battle Mountain, but in the McCoy area the Belden shale is not present and the coarse clastics rest on the Leadville limestone. The Weber shale, Weber grit, and Maroon formation of the Leadville and Alma districts on the south and southeast are equivalent to the Battle Mountain, but here also, as in the McCoy area, definite horizon markers which can be carried from one area to another have not been found. This is partly due to the fact that the clastic sediments vary greatly in thickness and lithology along the strike, and that the non-clastic sediments are lenticular and thus are difficult to trace over large areas. Fossils are relatively scarce and seem to be more or less the same throughout the section; thus faunal zones can not be used for correlation purposes. The Battle Mountain is probably the equivalent of the Weber formation, the Coffman conglomerate, and perhaps part of the Chubb siltstone of the Salt Creek area (8). It is the same age as the

McCoy formation and most if not all of the Maroon formation of the Dotsero region on the west (2).

In the vicinity of Glenwood Springs, Garfield County, there are approximately 4,500 feet of late Paleozoic clastic sediment interbedded with gypsum and thin limestones. The lowest 600 feet is composed of dark shale and fossiliferous limestone and is very probably correlated with the Belden shale member. The overlying brown and red clastics seem to be unfossiliferous, but are apparently of the same age as the Battle Mountain formation. Exact correlation at present is difficult because these coarse sediments were derived from a source at the north or west (or perhaps from both directions); whereas those in the Gore area came from the east and northeast.

State Bridge formation.—The name State Bridge is proposed by Donner (4) for about 500 feet of red and gray siltstones and shales lying conformably above the McCoy formation and disconformably below the Triassic Shinarump conglomerate, ¼ mile north of the State Bridge Hotel, Eagle County. The type section follows.

TYPE SECTION OF STATE BRIDGE FORMATION

Measured by H. F. Donner, 1936

South slope of Harmony Mountain 0.3 mile north of State Bridge, Colorado

Triassic: Shinarump conglomerate

Disconformable contact with State Bridge formation

Pennsylvanian or Permian: State Bridge formation

Interval Number		*Thickness in Feet*
6	Siltstone and shale micaceous, calcareous, brick-red	86
5	Siltstone and shale, siltstone calcareous, ripple-marked, purple-gray. Some of shale gray mottled with purple	53
4	Shale and siltstone, shale thin-bedded, siltstone calcareous; yellow and light gray	88
3	Siltstone micaceous, calcareous, with interbedded shale and thin arenaceous limestone beds; brick-red	150
2	Sandstone very calcareous ledge-former, light gray; pelecypods, *Myalina, Pleurophorus, Aviculopecten**	7
1	Shale with interbedded micaceous siltstone; brick-red with some gray beds	141
	Total	525

Conformable contact with McCoy formation

* Fossils collected by present writer.

In the north part of the Gore area about 15 miles south of the type section, the formation consists of ripple-marked, red siltstones resting conformably on the Battle Mountain formation. On the North Fork of Piney River it is 225 feet in thickness, and 6 miles southwest on Red and White Mountain it is about 750 feet thick. Just west of Wolcott, Eagle County, about 15 miles west of the area, there are about 1,100 feet of fine sandstone, siltstone, and shale just below the Shinarump conglomerate, which are in part State Bridge in age.

The presence of fine sandstones and siltstones intercalated with conglomeratic grits and coarse sandstones in that part of the Battle Mountain formation which lies above the Jacque Mountain limestone member suggests that siltstone dep-

osition may have been taking place in the basin on the west during late Battle Mountain time. It is possible that the lower part of the 1,100 feet of siltstone and sandstone deposited in the vicinity of Wolcott may be an offshore, fine-grained facies of the upper Battle Mountain. In other words, there may have been a change of lithologic facies westward from the Front Range highland, the time lines thus crossing the lithologic lines. An alternative explanation lies in the assumption that the siltstone thins from Wolcott eastward to the North Fork of Piney River at the rate of 80–100 feet to the mile, because of the erosion of the upper part of the formation east of Wolcott. If this were true, the angular discordance between the State Bridge formation and the overlying Triassic would be about 1°, which would not be noticeable in a small outcrop. This explanation necessarily assumes that the gypsum beds rise in the section west of the Gore area, because the Wolcott sequence lies above contorted gypsum beds. At present, the writer believes that the first explanation is the more plausible.

A study of the petrologic character and the lower and upper contacts of the State Bridge formation in the Gore and adjacent areas will be necessary to determine the exact lateral relations. According to Paul D. Krynine,[8] the State Bridge and Battle Mountain formations have the same mineral content and differ only in grain size.

Specimens of the pelecypods *Myalina*, *Aviculopecten*, and *Pleurophorus* have been found in association with a thin algal limestone in the lower part of the type section of the State Bridge unit. According to Newell,[9] these pelecypods are not early Pennsylvanian in age, but may belong to the middle or upper part of this system, or to the Permian.

Judged from the smaller grain size of the clastic sediments, the Ancestral Rockies appear to have been reduced at this time. The pelecypod fauna and algal flora are suggestive of shallow marine or brackish-water conditions.

Possibly the State Bridge is equivalent to the Pony Spring siltstone member of the Maroon formation, composing the upper part of an 8,000-foot section of siltstone and fine clastics in the Salt Creek area (8), and to the upper part of the Maroon formation of the Alma district. These correlations are based on lithologic similarity and stratigraphic position. There are about 950 feet of fine and medium-grained, red sandstone and red siltstone in the uppermost part of the Paleozoic section at Dotsero. Bassett (2) suggests that these sediments may be State Bridge in age.

This formation is here correlated with strata that have been considered to be Permian (?) in age by many workers. There is, however, no indisputable evidence that any of the Maroon is Permian in age. The State Bridge formation in the Gore area is considered to be either middle or late Pennsylvanian or Permian in age.

[8] Written communication, April 22, 1939.

[9] Norman D. Newell, written communication, March 9, 1939.

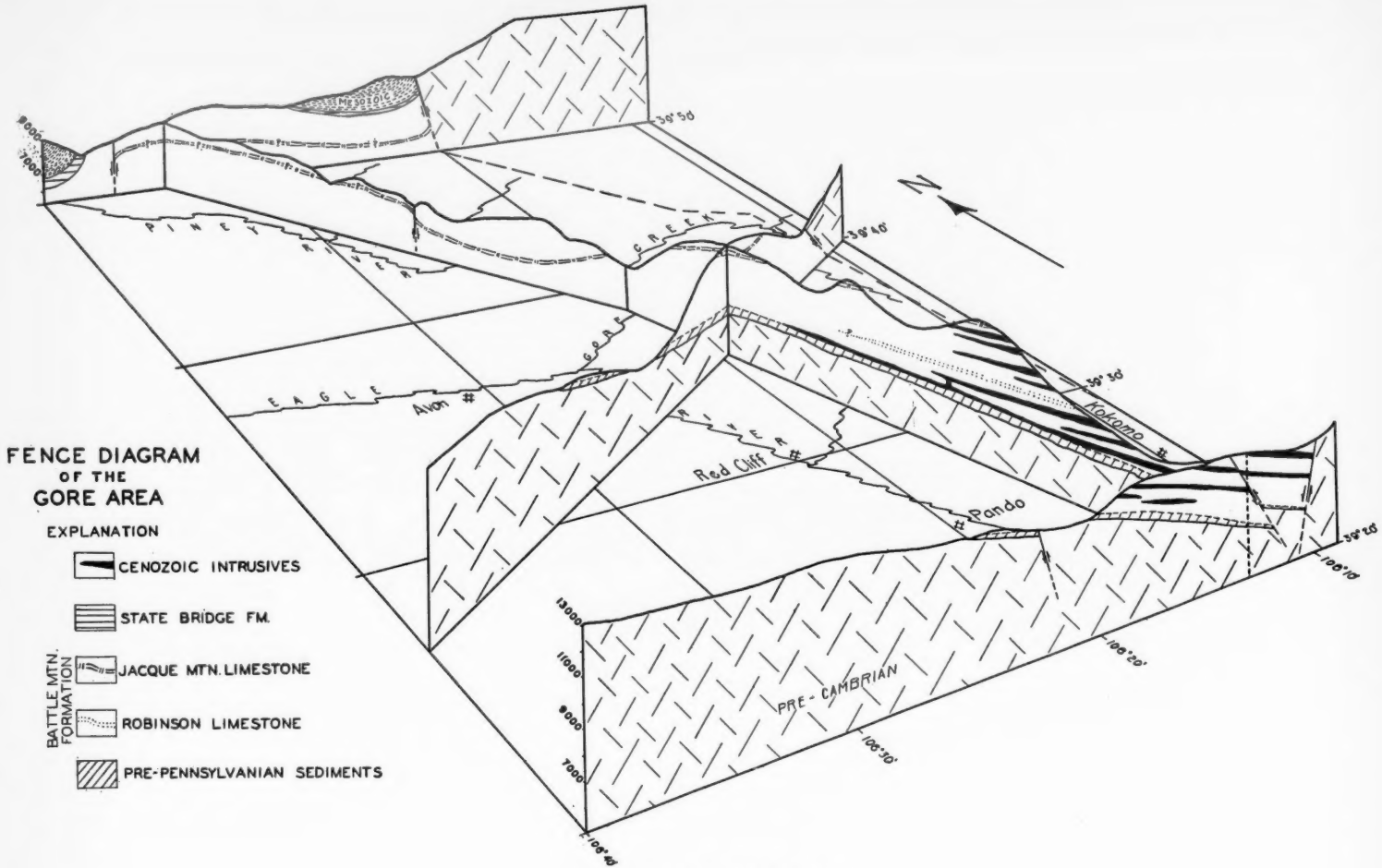

FIG. 4.—Fence diagram of Gore area.

MINOR STRUCTURAL FEATURES

Aside from the Gore and Mosquito faults which are high-angle reverse faults, there are numerous small faults most of which have vertical or nearly vertical dips. One of these is found along the east side of Chicago Ridge, 4 miles west of Climax. Its strike is about N. 13° W. Two nearly vertical faults leave the Gore fault just west of Bald Mountain, and extend across Gore Creek near the mouth of Mill Creek. Two prominent high-angle faults striking northeast cross Piney River near the north end of the area. The throw of these faults has not been determined accurately.

GEOLOGIC HISTORY

Various maps showing Pennsylvanian stratigraphy in Colorado have been presented in the literature, such as those by Melton (16) in 1925, Lovering (14) in 1929, Johnson (10) in 1929, VerWiebe (21) in 1930, and Heaton (9) in 1933. The present writer's observations concur with those of Lovering.

The character of much of the pre-Pennsylvanian sediments in Colorado suggests that the local land areas were low, and therefore furnished relatively little coarse material to the basins of sedimentation. After the deposition of the Leadville limestone of Mississippian age, there was an interval of subaerial erosion during which the exposed limestone was channeled and pitted by solution. At Gilman a veritable karst topography was developed. Near Volcano Siding, north of McCoy, caves were formed in the limestone which became filled with Pennsylvanian redbeds. If the Leadville was the last Mississippian formation deposited in the area, then the stratigraphic hiatus between it and the Belden shale member represents the time extending from Osage to the late Bend or early Des Moines epoch.

That the Mississippian limestone at one time covered the Ancestral Rockies is a controversial point. Baker, Dane, and Reeside (1) say that it covered the Uncompahgre highland; on the other hand, Johnson (10) states that the Mississippian did not extend across this region. Most students believe that the Front Range highland was not an area of deposition at this time. This belief is based on the thinning and overlap of the limestone on the flanks of the uplift (9, 14, 15). It is not known that the Sawatch highland was covered by the Leadville limestone.

In early Pennsylvanian time the Belden shale member was deposited in a marine invasion from the south or southeast. The carbonaceous shale, thin limestone and dark sandstone of the Belden suggest that the Ancestral Rockies were low, but higher than in Mississippian time. The presence of *Lepidodendron*, *Sigillaria*, and *Calamites* and small coal beds in parts of the Belden member indicate swamp conditions and a relatively mild climate.

Uplift in the Ancestral Rockies in Cherokee time resulted in the deposition of the coarse, arkosic sandstones, and conglomeratic grits of the Battle Mountain formation in this part of the trough. Crossbedding and numerous intraformational

unconformities in this formation imply discontinuous deposition by shifting streams in subaerial or shallow-water parts of deltas. Interbedded marine limestone and shale indicate marine deposition along the outer margin of the deltas. The great thickness of clastic deposits seems to bear out the opinion that the downwarping of the trough occurred concomitantly with the uplift of the adjacent highlands (8, 15), which had a fairly high relief.

A climatic change may have taken place with the rise of the highlands in Battle Mountain time. This is suggested by the appearance of a flora of a dry-soil habitat and the formation of extensive gypsum deposits in the Eagle Basin. Tieje (20) has suggested that the Fountain formation, a probable equivalent of the Battle Mountain formation on the east side of the Front Range, was deposited under semi-arid conditions.

In Marmaton time acceleration of uplift of the highlands caused the coarse clastic sediment of the upper Battle Mountain formation to fill the trough.

In State Bridge time, either the highlands were lowered or the amount of precipitation diminished, or perhaps a combination of the two resulted in a decrease of grain size of the clastic sediment, and siltstone and shale, rather than conglomeratic grit were deposited. The presence of ripple-marked siltstone interbedded with thin calcareous beds bearing pelecypods of marine or brackish-water origin suggests deposition in shallow water close to shore. Inasmuch as the exact age of the State Bridge has not been established, it is not possible to say whether these upper redbeds are late Pennsylvanian or Permian in age.

The unconformable contact between the State Bridge and the Triassic rocks indicates that some erosion took place before Upper Triassic time. Just how much material was removed is not known. During Upper Triassic, Upper Jurassic, and Upper Cretaceous times, sediments accumulated in this region.

During the Laramide orogeny, thrusting and uplift caused faulting along the Gore and Tenmile ranges. These faults are part of a group of high-angle structures arranged *en échelon*, trending northwest from Salida in Chaffee County to Steamboat Springs in Routt County. In the Gore area, the drag on the west sides of the Gore and Mosquito faults caused a synclinal structure. Doubtless, most of the small faults in the area were formed at the same time, as a relief to stresses set up during the orogeny. Uplifts at various times in the Cenozoic resulted in movements along old fault lines.

Intrusion of Pennsylvanian strata by numerous porphyry sills and dikes took place in late Cretaceous (Denver) and early Cenozoic time (Fig. 4). These intrusions altered the sediments noticeably in certain parts of the area. In the Miocene, lavas were extruded just north of the Gore area.

Pleistocene glaciation modified the topography and altered the drainage to some extent.

SUMMARY

The formational names Weber and Maroon are abandoned in the area and the term Battle Mountain formation proposed to replace them. The name Belden

shale member is proposed for the lower part of the Battle Mountain formation. This name replaces the term Weber shale. Much of the Battle Mountain formation, which consists of 4,000–6,600 feet of clastic sediment, is shown to be early Pennsylvanian (Des Moines) in age. The name State Bridge formation is applied to the upper redbeds, which lie between the Battle Mountain formation and the Triassic. The State Bridge formation is middle, or late Pennsylvanian or Permian in age.

At least a part of the gypsum of the Eagle Basin on the west is shown to be Des Moines in age.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 26, NO. 8 (AUGUST, 1942), PP. 1398-1409, 4 FIGS.

SUBSURFACE STUDY OF ELLENBURGER FORMATION IN WEST TEXAS[1]

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ABSTRACT

Various parts of the Ellenburger (Cambro-Ordovician) formation have been penetrated within the West Texas area bounded by Latitude 32° and 30° and Longitude 101° and 103°. The formation consists of fine to coarsely crystalline dolomites and dense limestones. These lithologic units are of little value even in local correlations when accurate work is desired.

A careful study has been made of the insoluble residues from most of the well cuttings available. The chief criterion for correlations is chert. Four main classes of chert are recognized: smooth, granular, chalky, and drusy. Each class may have several secondary characteristics, and gradational types are present. From this work the complete Ellenburger section, which is approximately 1,335 feet thick in western Crane County, has been divided into five zones.

Chert zones have made it possible to locate accurately the stratigraphic position entered in the dolomite section. The upper part of the Ellenburger has been truncated in four wells in the Big Lake field (Reagan County). Restoration of the truncated part shows the axis of the folding to be parallel with the Permian folding (San Andres) which extends northwest and southeast rather than north and south.

Approximately 275 feet of Ellenburger is absent from the base against the Apco Ridge (Pecos County) probably due to overlap, and about 900 feet has been eroded from the top of the section in this area.

The Ellenburger formation (Cambro-Ordovician) was named by Sidney Paige[3] from the outcrop in the Central Mineral region of Texas. The formation consists mostly of fine to crystalline dolomite, dense limestone, secondary anhydrite, and some sand and shale streaks. The standard section for the West Texas area is found in Loffland Brothers *et al.* J. B. Tubb well No. 3, Sec. 9, Block B-27, P.S.L. Survey, Crane County. The Ellenburger is 1,303 feet thick here, and approximately 20–30 feet of Ellenburger has been removed by erosion from the top, which allows a thickness of about 1,325 feet in the type section of West Texas.

Oil was discovered in the Ellenburger in the Big Lake field, Reagan County, in 1930. Since that date approximately 30 million barrels of oil have been produced from the 24 wells. Oil has since been found in two pools in the Sand Hills[4] field of central Crane County; in the Apco[5] field of north-central Pecos County; in the Abell field of north-central Pecos County; in the Barnhart field of southeastern Reagan County; in an unnamed pool south of the South Sand Hills pool, in which the Gulf Oil Corporation's Waddell *et al.* No. 17 was the discovery well; and in one wildcat well, the Culbertson and Irwin Corporation's Mary Heiner No. 1, in west-central Pecos County.

[1] Read before the Geological Society of America at Austin, December 27, 1940, and before the Association at Houston, April 16, 1941. Manuscript received, December 6, 1941.

[2] Research geologist, University Lands.

[3] Sidney Paige, "Description of the Llano and Burnet Quadrangles," *U. S. Geol. Survey Geol. Atlas Folio 183* (1912).

[4] C. D. Cordry, "Ordovician Development, Sand Hills Structure, Crane County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 12 (December, 1937), pp. 1575–91.

[5] Taylor Cole, "Ordovician Development, Apco Structure, Pecos County, Texas," *ibid.*, Vol. 24, No. 3 (March, 1940), pp. 42–45.

The Ellenburger formation has been studied in various ways by different workers. Dake and Bridge[6] have recognized in the central mineral region faunal units which correspond with the following Missouri equivalents: Cotter, Jefferson City, Roubidoux, Gasconade, Eminence, Potosi. Leo Hendricks[7] and M. G. Cheney[8] have studied insoluble residues of the formation obtained both from surface outcrops and well cuttings in the north and central Texas areas.

The writer's work on the Ellenburger has been essentially subsurface study. The closest outcrop of Ellenburger is about 150 miles east of Big Lake while the closest outcrop (the Van Horn region) is about 120 miles west of the Apco field. Synclinal facies of the lower Ordovician are found in the Marathon region, 65 miles southwest of the Apco field.

The study by the writer has been chiefly an investigation of the insoluble residues of the formation. Because limestone beds are not persistent in the Ellenburger, and the dolomites are similar throughout the group, unsatisfactory results are obtained in correlating wells in the Ellenburger based on differentiation of dolomite and limestone. The success that various workers[9] have had with the use of insoluble residues is well known and is not discussed here. The method of preparation and examination has been essentially like that of other workers. The samples were dissolved in dilute hydrochloric acid after being weighed. They were weighed after digestion and the percentage of residue by weight obtained for each sample. Only in a very few correlations, however, did the quantitative results check the qualitative results, and it is the writer's opinion that when drill cuttings are used it is a waste of time to obtain the percentage of insoluble material present in the sample. The residues were examined under a 24-power binocular microscope and descriptions were plotted on well-log strips in much the same manner as ordinary cuttings logs are made in West Texas. A different color is used for each of the four classes of chert with appropriate symbols for various secondary characteristics of the chert. Various colors are used for the sand, shale, silt, anhydrite, pyrite, *et cetera*. By careful description and plotting of residues, it is possible to make more minute correlations than by merely zoning the formation on the

[6] C. L. Dake and Josiah Bridge, "Faunal Correlation of the Ellenburger Limestone of Texas," *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 725–41.

[7] Leo Hendricks, "Subsurface Divisions of the Ellenburger in North-Central Texas," *Univ. Texas, Bur. Econ. Geol. Bull. 3945* (1940), pp. 923–68.

[8] M. G. Cheney, "Geology of North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), pp. 65–118.

[9] H. S. McQueen, "Insoluble Residues as a Guide in Stratigraphic Studies," *Missouri Bur. Geol. Mines 56th Bien. Rept.* (1931), Appendix 1, p. 102.
H. S. Martin, "Insoluble Residues of Some Mississippian Limestones of Western Kentucky, *Kentucky Geol. Survey*, Ser. vi, Vol. 41 (1931), p. 133.
Kendall E. Born and H. B. Burwell, "Geology and Petroleum Resources of Clay County, Tennessee," *Tennessee Div. Geol. Bull. 47* (1931), pp. 20–57.
M. G. Cheney, *op. cit.*
Hubert Andrew Ireland, "Use of Insoluble Residues for Correlation in Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 8 (August, 1936), pp. 1086–1121.
Leo Hendricks, *op. cit.*

basis of the chert or from correlating original cuttings. The residue log form now being used contains two columns, one for the original samples and one for the insoluble residues, with space to plot a histogram of the percentage of residues present.

The residues from the Ellenburger consist chiefly of chert and quartz; and accessory residues are mainly sand, silt, shale, anhydrite, glauconite, pyrite, and sulphur. Sphalerite was found in one sample in the Loffland well. The Ellenburger cherts are in general light-colored except in the lowermost part, where they are ordinarily brown and gray.

Table I was prepared by P. D. Moore and the writer to aid workers in this area.

TABLE I

CLASSIFICATION OF INSOLUBLE-RESIDUE TYPES AS APPLIED TO ELLENBURGER FORMATION CHERT

I. SMOOTH—Crypto-crystalline chert with sharp conchoidal fracture
- 1. Plain smooth
- 2. Dolocastic
  - A. Disseminated
    - a. Fine b. Medium c. Coarse
  - B. Skeletal
    - a. Fine b. Medium c. Coarse
- 3. Oölitic, pisolitic, spherulitic
- 4. Banded

II. GRANULAR—Crystalline chert varying from fine to coarse
- 1. Granular
  - A. Fine
  - B. Medium
  - C. Coarse
- 2. Dolocastic
  - A. Disseminated
    - a. Fine b. Medium c. Coarse
  - B. Skeletal
    - a. Fine b. Medium c. Coarse
  - C. Lacy, thready
- 3. Oölitic, pisolitic, spherulitic
- 4. Medium-granular—all species—some rare
- 5. Coarse-granular—all species—some rare

III. CHALKY—Amorphous, tripoli-like
- 1. Chalky
- 2. Dolocastic
  - A. Disseminated
    - a. Fine b. Medium c. Coarse
  - B. Skeletal
    - a. Fine b. Medium c. Coarse
- 3. Oölitic, pisolitic, spherulitic

IV. DRUSY—Translucent to clear recystallized chert or quartz
- 1. Drusy
- 2. Dolocastic
  - A. Disseminated
    - a. Fine b. Medium c. Coarse
  - B. Skeletal
    - a. Fine b. Medium c. Coarse
- 3. Oölitic, oöcastic, *et cetera*

V. GRADATIONAL TYPES
1. Smooth to drusy
2. Granular to drusy
3. Chalky to drusy
4. Various other combinations

SAND

VI. SAND		
1. Fine	Varieties	
	a. Angular	
	b. Sub-rounded	
	c. Rounded	
	d. Euhedral	
2. Medium	Same as above	
3. Coarse	Same as above	

SILT AND SHALE

VII. SILT AND SHALE	
1. Dolocastic	a. Any color
	b. Any structure
	c. Any texture
2. Porous	Same as above
3. Sandy	Same as above
4. Pyritic	Same as above
5. Micaceous	Same as above
6. Bentonitic	Same as above

ACCESSORIES

VIII. ACCESSORIES
1. Anhydrite, selenite, gypsum
2. Pyrite
3. Mica
4. Sand grains (imbedded in chert)
5. Iron oxides and carbonates (X-ray analysis)
6. Glauconite
7. Sulphur
8. Fossil casts

Several terms used in Table I are here defined.

Oöcastic refers to cavities which were formerly occupied by oölites. This is analogous to dolocastic.[10]

Disseminated—term used to refer to dolocasts (rhombohedral cavities) which are widely separated from each other.

Skeletal—term used to refer to dolocasts which are closely spaced.

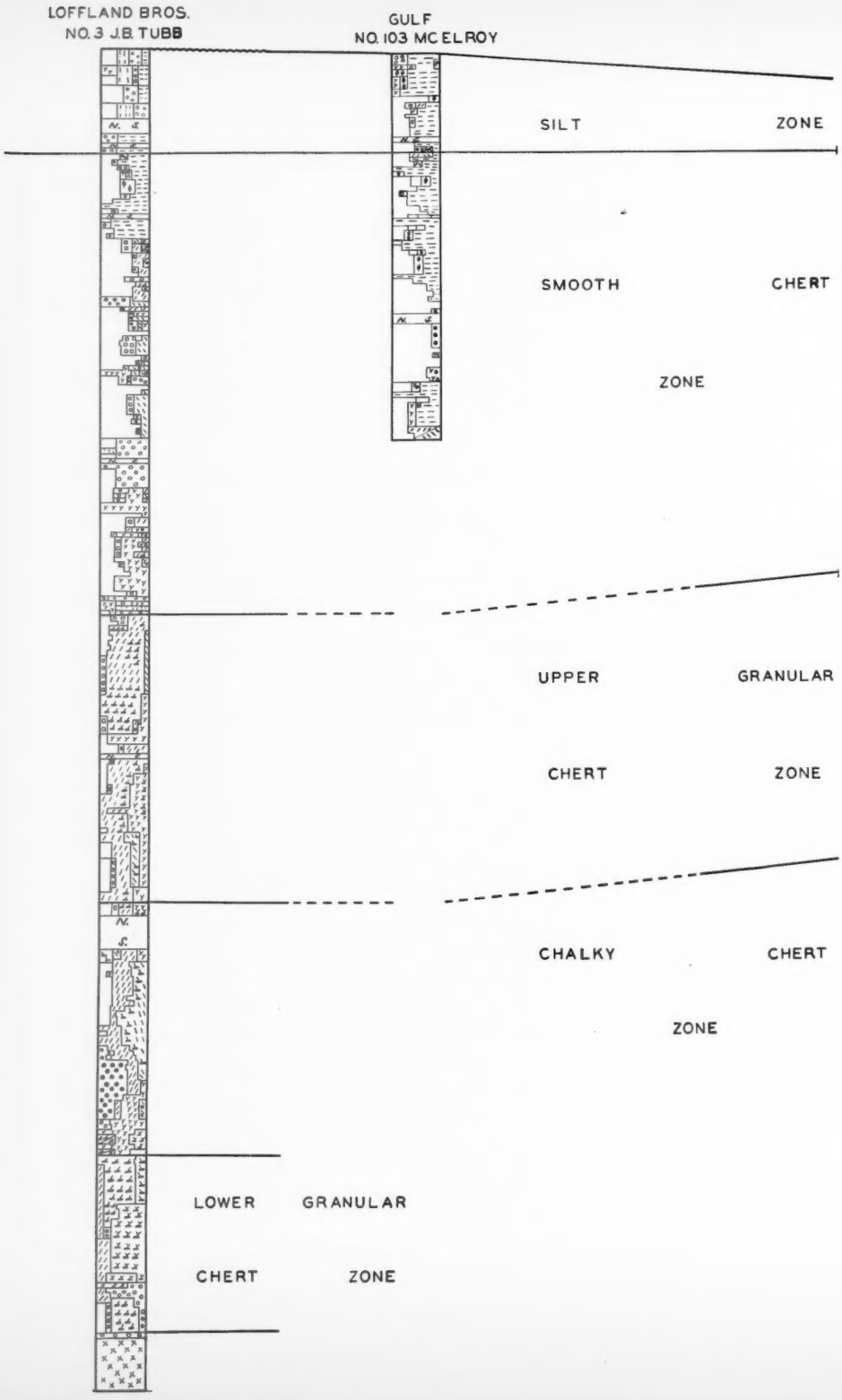
The terms fine, medium, and coarse may be used with either skeletal or disseminated to indicate the size of the dolocast.

Thus a specimen may be described as fine skeletal chert, indicating that it is dolocastic, that the dolocasts are small, and that they are closely spaced.

DIVISION OF ELLENBURGER IN WEST TEXAS

The Ellenburger of West Texas has been divided into five zones chiefly on the basis of the chert residues. Four main classes of chert have been used. These are differentiated by texture. Three of the classes are diagnostic: smooth, granular, and chalky. The fourth class is drusy chert which may be quartz or a recrystallization of any other type of chert. The smooth, granular, and chalky cherts are recog-

[10] Dolocast, cavity left after dissolving out dolomite crystal. See H. S. McQueen, *op. cit.*


LOFFLAND BROS.
NO. 3 J.B. TUBB
GULF
NO. 103 MC ELROY
SILT ZONE
SMOOTH CHERT
ZONE
UPPER GRANULAR
CHERT ZONE
CHALKY CHERT
ZONE
LOWER GRANULAR
CHERT ZONE

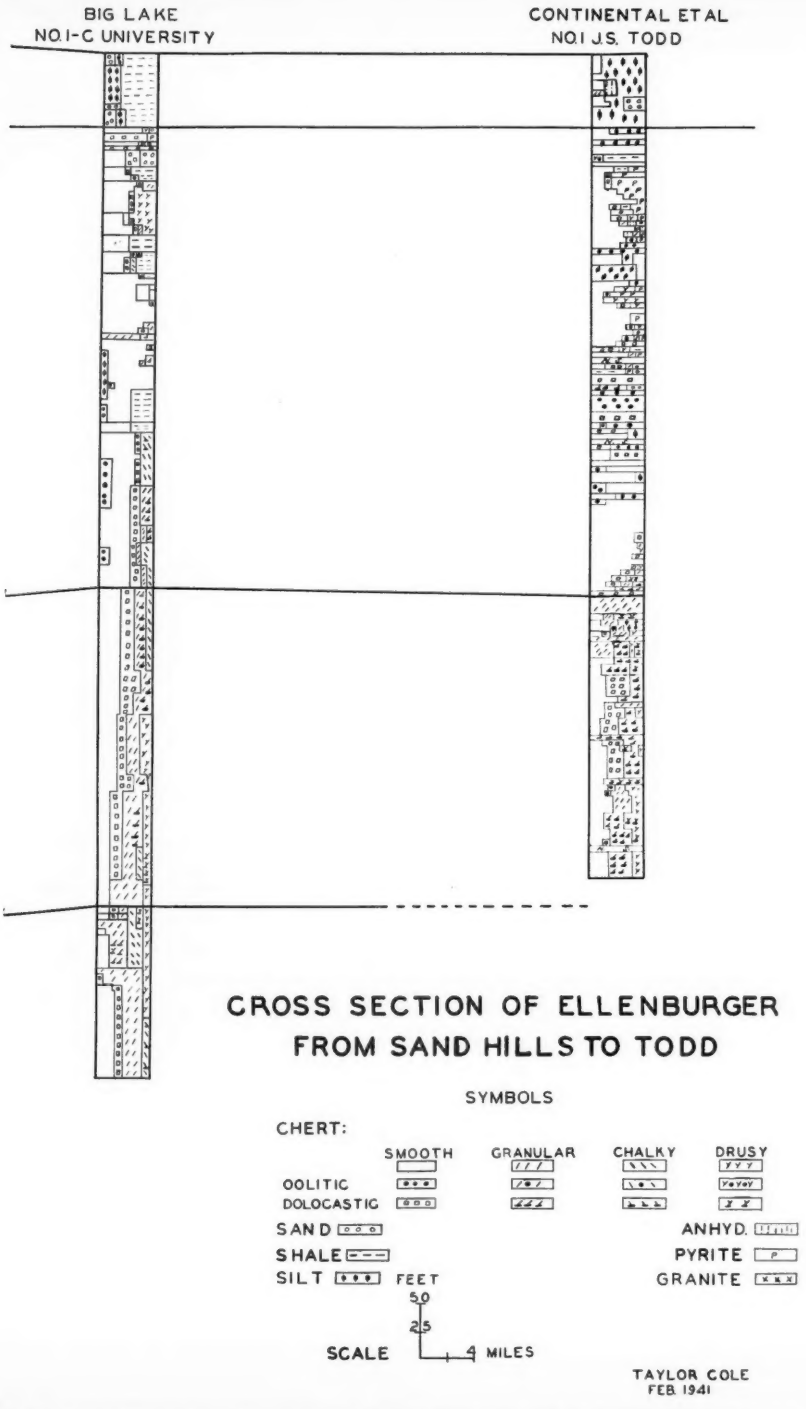


FIG. 1.—Cross section of Ellenburger from Sand Hills (Crane County) to Todd (Crockett County).

nized by the character of the crystallinity. In most specimens these are very readily and easily recognizable.

The following zones are recognized: silt zone, smooth chert zone, upper granular chert zone, chalky chert zone, lower granular chert zone.

A description of each zone taken mainly from Loffland Brothers' Tubb No. 3 in central Crane County is given in Table II.

Figures 1 and 2 are cross sections showing the zones present in the Ellenburger in the various fields and many of the wildcats in the West Texas area. The two cross sections show very well the uniformity in thickness of the smooth chert zone, upper granular chert zone, and chalky chert zone. The thinning in the silt zone is well shown in Figure 1.

TABLE II

Zone	*Main Chert Type*	*Other Common Cherts*	*Common Secondary Characteristics*	*Other Constituents*	*Thickness in Feet*	*Remarks*
Silt	Smooth—drusy	Smooth—rare	Non-dolocastic	Silt, ordinarily skeletal; some sand and shale	125	Zone of production in original Sand Hills field and is one of "pay" zones at Big Lake
Smooth	Smooth	Some drusy near base	Three oölite zones. Some disseminated and skeletal chert	Sand, shale, anhydrite	470	"Pay" zone in southeast Ordovician pool at Sand Hills and production in Gulf's Waddell *et al.* No. 17 is near top of zone. Heiner "pay" near base
Upper granular	Granular ordinarily fine granular	Some smooth near top and near base	Highly dolocastic; white to gray and to brown	Some sand occasionally	290	One "pay" zone in Big Lake field
Chalky	Chalky	Smooth, granular, and drusy	Amorphous to fine skeletal; one prominent oölite zone		255	Lower part is "pay" zone in Apco field
Lower granular	Granular ordinarily medium-granular	Drusy	Highly dolocastic buff to brown	Large rounded frosted sand grains near base	180	Most of chert has recrystallized to drusy chert

Correlations with the Missouri section have been made by Haseltine[11] and others familiar with the Cambro-Ordovician found in Missouri. Their correlation fits the chert zones approximately as follows.

Silt zone—Powell(?)

Smooth Chert zone { Cotter, Jefferson City, Roubidoux, Gasconade

Upper Granular Chert zone { Eminence

Chalky Chert zone { Potosi

Lower Granular Chert zone

The insoluble residues from West Texas resemble those of Missouri more than those of the central Texas section. The writer examined some of the residues and has come to the following conclusions. 1. The silt zone is younger than the Cotter as identified in central Texas or the Cotter residues from Missouri. 2. A

[11] W. Lloyd Haseltine, personal communication.

TABLE III
WELL CHART
(Figures in feet)

Name and Location of Well	Elevation	Top of Ellenburger	Penetration of Ellenburger	Approximate Thickness of Ellenburger Removed	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
CRANE COUNTY									
Gulf Oil Corp. *et al.* Tubb No. 1-A; Sec. 20 Blk. B-27, PSL Survey	2,548	5,760	23	165	Absent	5,760 to 5,783 T.D.			
Loffland Bros.' Tubb No. 3; Sec. 9, Blk. B-27, PSL Survey	2,540	5,802	1,303	20	5,802 to 5,910	5,910 to 6,380	6,380 to 6,670	6,670 to 6,925	6,925 to 7,105
CROCKETT COUNTY									
Continental Oil Co. *et al.* Todd No. 1-B; Sec. 30, Blk. WX, GC&SF Survey	2,507	6,257	753	None	6,257 to 6,325	6,325 to 6,755	6,755 to 7,010 T.D.		
GLASSCOCK COUNTY									
Moore Bros. *et al.* McDowell No. 1; Sec. 22, Blk. 34, T. 2 S., T & P Survey	2,534	10,345	560	743	Absent	Absent	10,345 to 10,465	10,465 to 10,720	10,720 to 10,905
PECOS COUNTY*									
Culbertson & Irwin's Mary Heiner No. 1; Sec. 589, SC & SF Survey	2,549	5,128	537	100	5,128 to 5,170	5,170 to 5,627	5,627 to 5,665 T.D.		
Magnolia Petrol. Co's. McKee No. 1; Sec. 24, Blk. 9, H & GN Survey	2,385	6,102	156	None	6,102 to 6,228	6,228 to 6,267 T.D.			
Olson Drlg. Co. & Bryce McCandless' Crockett No. 1; Sec. 5, Blk. 110, TCRR Survey	2,461	4,410	108	1,046	Absent	Absent	Absent	4,410 to 4,507	4,507 to 4,523
REAGAN COUNTY									
Big Lake Oil Co's. University No. 1-C; Sec. 1, Blk. 2, University Lands Survey	2,731	8,618	832	None	8,618 to 8,683	8,683 to 9,105	9,105 to 9,395	9,395 to 8,715 T.D.	
Big Lake Oil Co's. University No. 5-C; Sec. 25, Blk. 9, University Lands Survey	2,697	8,350	520	None	8,350 to 8,415	8,415 to 8,845	8,845 to 8,872 T.D.		
Big Lake Oil Co's. University No. 9-C; Sec. 12, Blk. 2, University Lands Survey	2,674	8,315	332	390	Absent	8,315 to 8,420	8,420 to 8,647 T.D.		
Big Lake Oil Co's. University No. 15-C; Sec. 12, Blk. 2, University Lands Survey	2,677	8,415	194	365	Absent	8,415 to 8,545	8,545 to 8,603 T.D.		
Big Lake Oil Co's. University No. 16-C; Sec. 25, Blk. 9, University Lands Survey	2,684	8,350	100	442	Absent	8,350 to 8,405	8,405 to 8,450 T.D.		
Texon Oil & Land Co's. University No. 9-B; Sec. 36, Blk. 9, University Lands Survey	2,735	8,575	275	275	Absent	8,575 to 8,795	8,795 to 8,850 T.D.		
UPTON COUNTY									
Gulf Oil Corp's. McElroy No. 103; Sec. 107, Blk. F, CCSD & RGNG Survey	2,633	12,391	395	None	12,391 to 12,483	12,483 to 12,786 T.D.			
WARD COUNTY									
Gulf Oil Corp's. Wristen No. 5; Sec. 18, Blk. 5, H & TC Survey	2,501	9,002	185	None	9,102 to 9,125	9,125 to 9,187 T.D.			

* Most Apco field wells included in article by Taylor Cole, "Ordovician Development, Apco Structure, Pecos County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 3 (March, 1940).

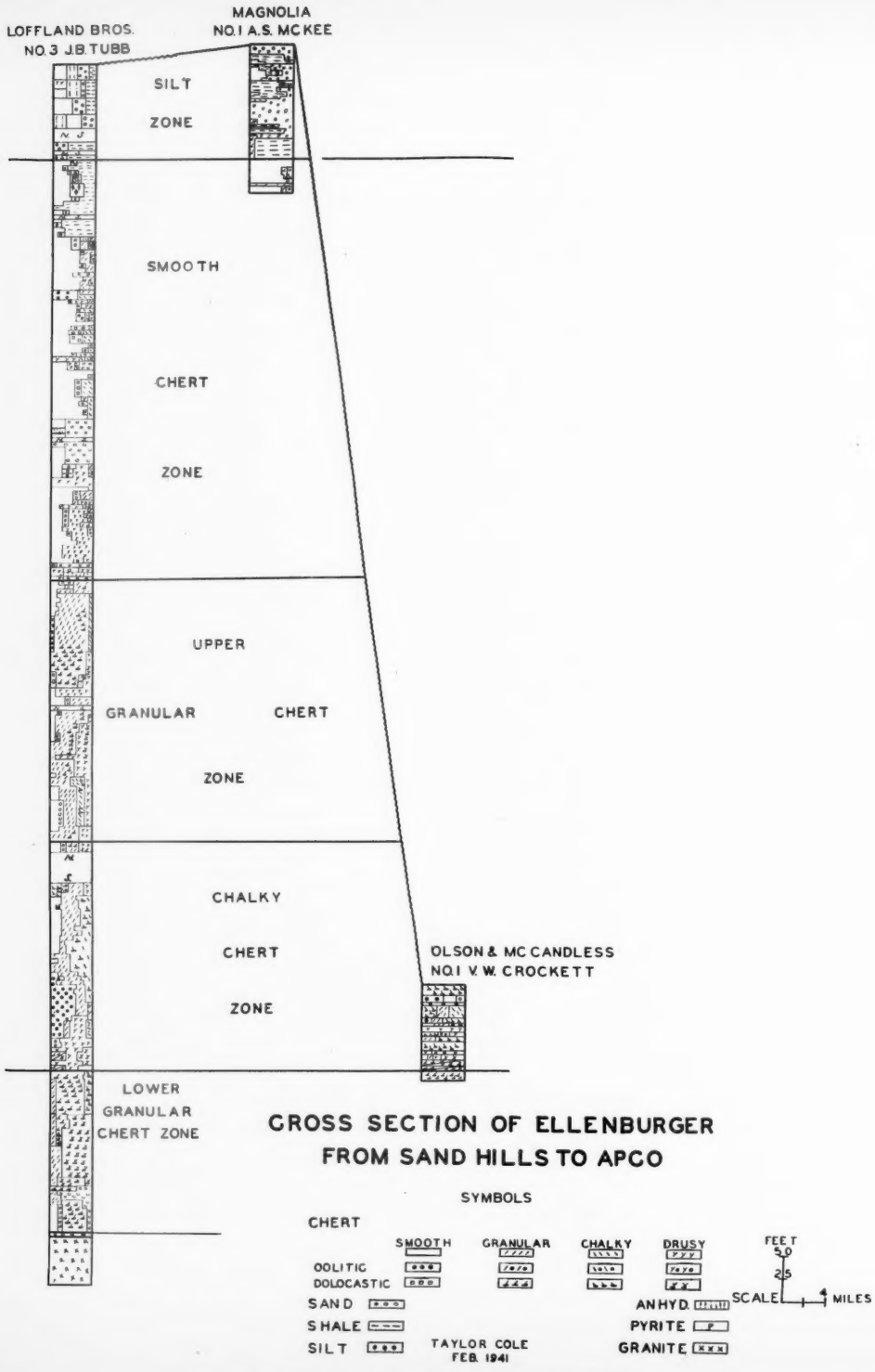


FIG. 2.—Cross section of Ellenburger from Sand Hills (Crane County) to Apco (Pecos County).

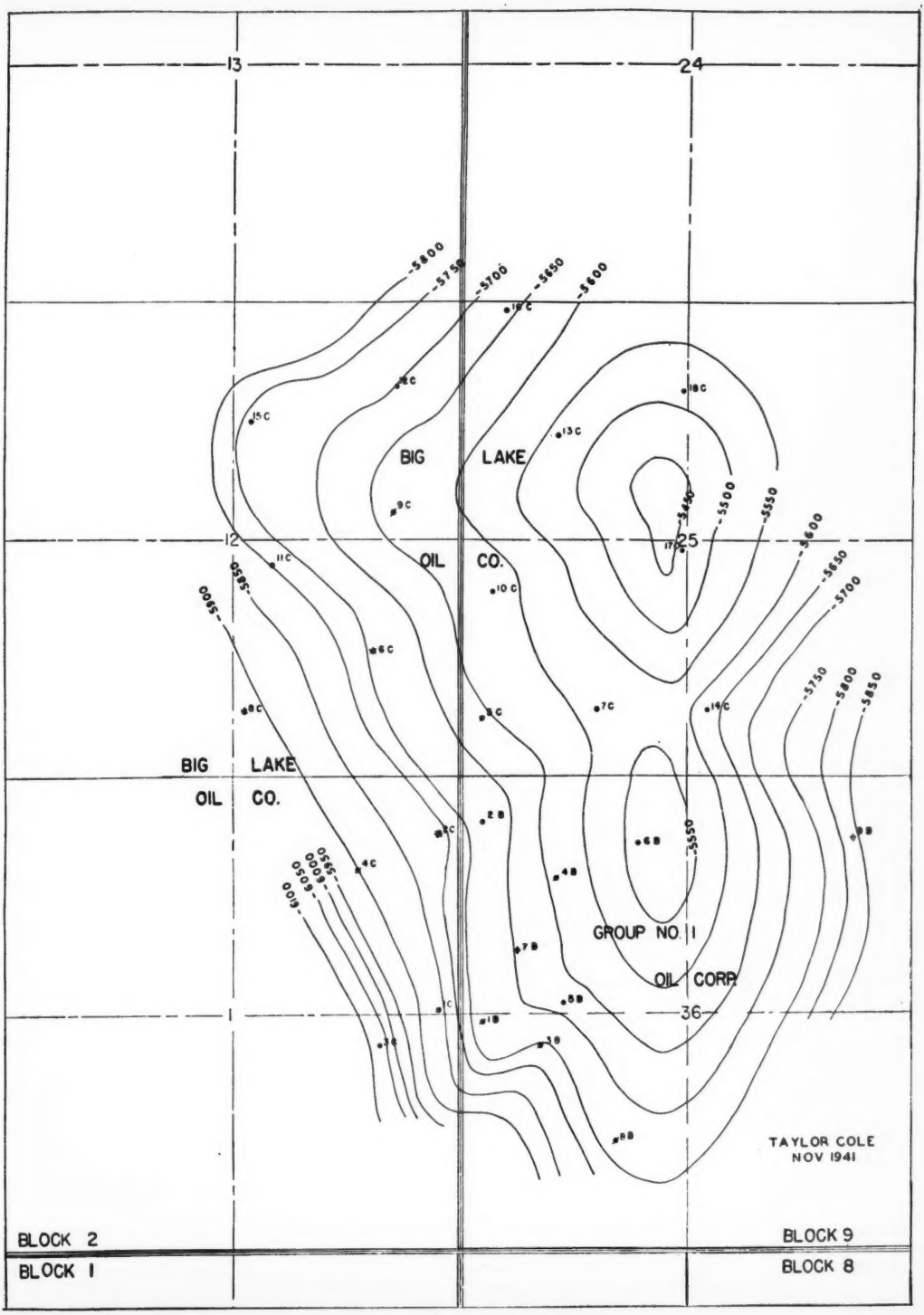


FIG. 3.—Structure map of Big Lake field. Datum: top of Ellenburger. Contour interval: 50 feet.

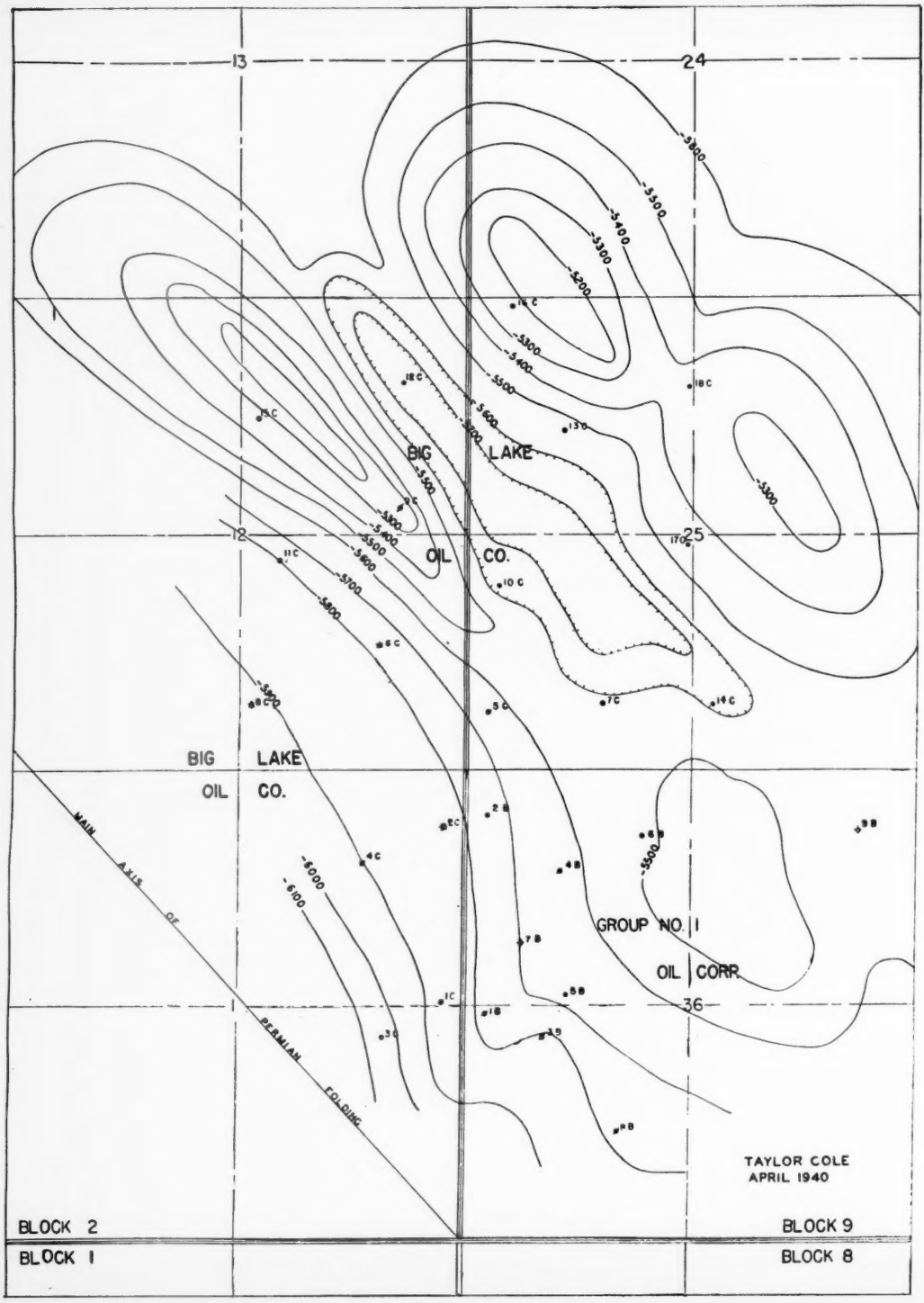


FIG. 4.—Structure map of Big Lake field. Datum: restored top of Ellenburger. Contour interval: 100 feet.

part of the West Texas Ellenburger section is Cambrian in age. That is, Eminence and Potosi residues are found in Loffland Brothers' Tubb No. 3 and in the Stanolind Oil and Gas Company's Conry-Davis No. 1 in north-central Pecos County.

Studies of insoluble residues show it is possible to determine what part of the Ellenburger was encountered in almost all the wells which have entered this formation. Producing areas where part of the Ellenburger is present, are: Big Lake, Apco, Sand Hills, Heiner, and Barnhart.

Figure 3 is a map of the Big Lake field with the top of the Ellenburger used as the datum. This map is really a topographic map of the Ellenburger. The main axis of the folding as shown here trends north and south. This axis makes a 45°-angle with the main axis of the Permian limestone (San Andres) folding.

Figure 4 is a map of the Big Lake field showing the writer's interpretation of the reconstructed Ellenburger structure. The axis of the folding trends northwest and southeast and parallels the Permian folding, although they offset each other about one mile. The Ordovician axis is northeast of the Permian axis. This map was made 1½ years before the last well was drilled in this field, No. 18-C. This well fits perfectly on the reconstructed map and indications are that there are 4–10 good locations left to be drilled at the north end of this structure. Certain conclusions may be drawn from a comparison of the Permian and Ordovician folding here: (1) the lines of folding seem to be parallel; (2) the highest Permian folds do not necessarily overlie the highest part of the Ordovician structure; (3) dips of 2,000 feet to the mile are not exceptional in the Ellenburger.

In the Todd field of Crockett County, the Permian and Ordovician folding are parallel and they offset each other about a mile. Here, however, the Permian axis is northeast of the Ordovician axis.

The Ellenburger has been found to lose section from the base by overlap or wedging against the Apco[12] Ridge. One well has lost about 225 feet and another about 125 feet in this manner, while Anderson-Prichard's Boren wells southwest of the Apco pool show overlapping as well as possible faulting in the Ellenburger.

The Ellenburger has been studied by all known practical methods, but it is believed by the writer that the best means available for solution of intra-formational correlation problems of the Ellenburger is a study of its insoluble residues.

Table III lists many of the wells in West Texas which have drilled an appreciable part of the Ellenburger.

[12] Taylor Cole, *op. cit.*

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VOL. 26, NO. 8 (AUGUST, 1942), PP. 1410-1413, 1 FIG.

GEOLOGICAL NOTES

GRAPHIC ARRANGEMENT OF A SYMPOSIUM ON PETROLEUM DISCOVERY METHODS[1]

C. DON HUGHES[2]
Amarillo, Texas

On January 5, 1942, A. I. Levorsen, chairman of the research committee of the American Association of Petroleum Geologists, sent copies of a letter to more than 500 members and associates of the Association, asking the question ". . . , what in your judgment is the best approach to the problem of oil and gas discovery?" The question was fully developed in the letter.

Excerpts from about 200 replies made up the annual research committee round-table discussion on Tuesday evening, April 21, 1942, at Denver, Colorado.

The full text of the letter and the excerpts from the replies were published by the Association in a 164-page *Report of a Symposium on Petroleum Discovery Methods*, dated April 1, 1942, which was made available immediately after the research committee round-table meeting, April 21, 1942.

The excerpts in the published report have been studied rather hurriedly by the writer and the responses which were favorable to a given method classified in order to construct a graphic picture of the results of the survey. Comments from 170 of the excerpts were used in the accompanying graph. In many cases, responses favorable to more than one method occurred in one excerpt. These were tallied under the various divisions.

Liberal interpretations were made in order to classify the responses, for example, reference to more paleogeographic studies, or to more studies of sedimentation were tallied under "stratigraphic" on the assumption they would aid primarily in finding stratigraphic traps.

Overlapping of classifications exists under the subdivisions in "geology," for example "stratigraphic" studies fall largely into the more general heading of "subsurface"; also "slim holes" are definite aids to both "stratigraphic" studies and to "subsurface" in general.

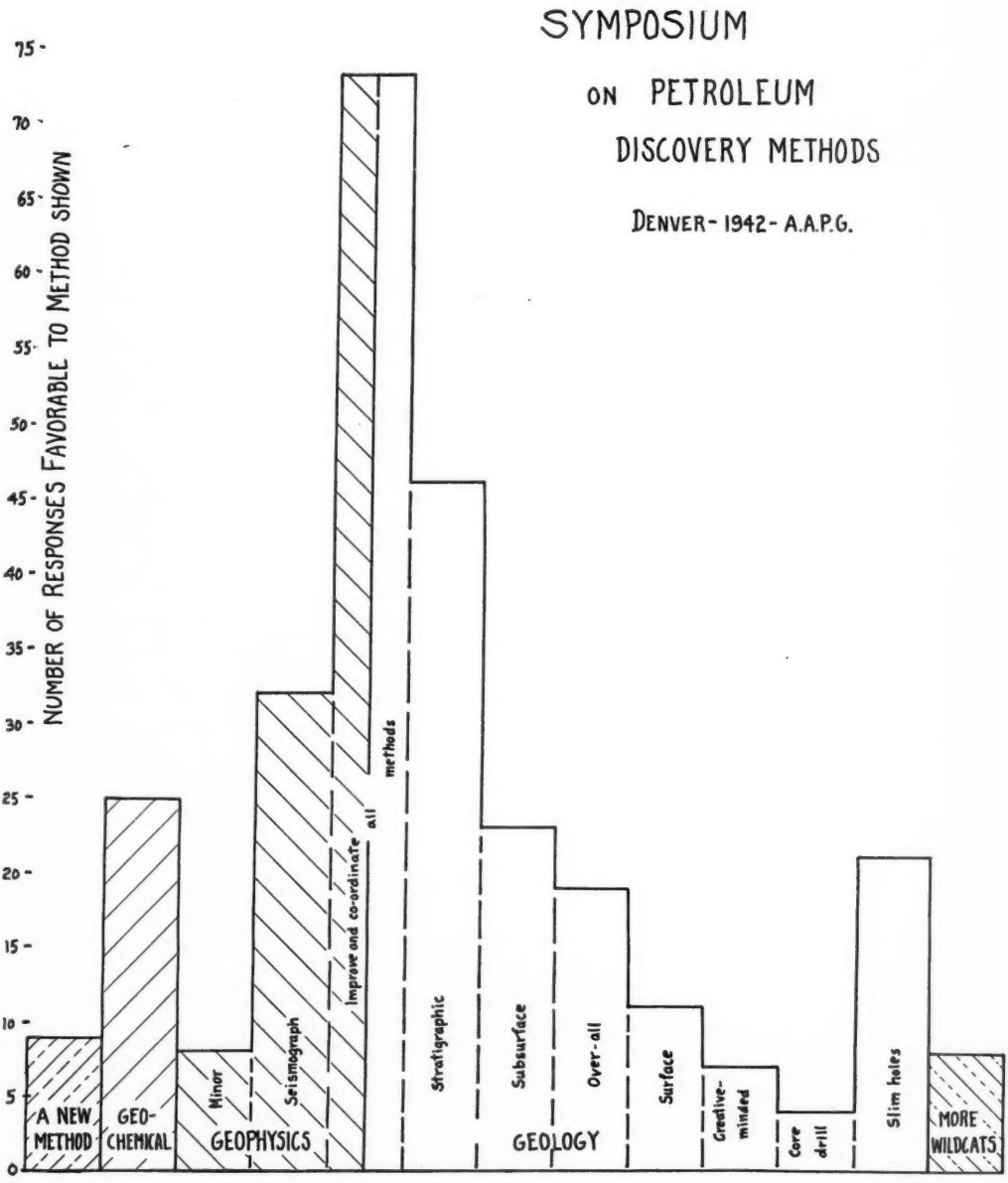
Comments on "geochemical," mostly soil analysis, ranged all the way from those highly in favor of it to those thinking it a failure, although the majority of those commenting on it were favorable.

The writer purposely excluded the few comments relating to Government and the Industry because of the desire to picture the methods looked upon currently with most favor.

No attempt was made by the writer to weigh the responses according to the ages, the professional standings, or the financial ratings of the members contribut-

[1] Manuscript received, June 13, 1942.

[2] Geologist, 1901 Van Buren.



INTERPRETATION OF RESPONSES AND GRAPHIC ARRANGEMENT BY C. Don Hughes.

FIG. 1

ing to the symposium. It is understood that the letters were originally sent to a representative group of the Association.

UPPER PENNSYLVANIAN ANHYDRITE, WEST TEXAS[1]

ROBERT ROTH[2]
Wichita Falls, Texas

One of the concepts resulting from the geological exploration of West Texas is that anhydrites are not known to occur in sediments older than Permian. However, new information obtained from the Humble Oil and Refining Company's Matador Land and Cattle Company No. 2 changes this concept. This well, located 660 feet from the south and west lines of Sec. 5, Block 1, Shock and Arnold Survey, Dickens County, Texas, was completed as a dry hole in the latter part of May, 1942. The following stratigraphic sequence was encountered.

Thickness in Feet		
	250	Recent Wind-blown unconsolidated sands with gravels in lower part
		PERMIAN
560		GUADALUPE
	560	Custer group
	70	Quartermaster formation Terra-cotta shale containing minor selenite. At base of formation, a zone of several feet containing large frosted sand grains
	10	Saddlehorse lentil, anhydrite with pink laminations
	480	Whitehorse formation
	300	Terra-cotta shale, massive beds of anhydrite with minor orange polished sandstone
	20	Dozier lens, porous coarsely oölitic pink magnesian limestone and many large frosted sand grains
	160	Terra-cotta shale with massive beds of anhydrite and orange polished sandstone
2,880		LEONARD
	1,260	Pease River group*
	560	Dog Creek formation
	290	Reddish brown shale, sodium chloride, and minor anhydrite. Several beds of fine angular sandstone with reddish cast
	270	Anhydrite and dolomite with minor reddish brown shale
	440	Blaine formation Anhydrite and dolomite. Some dolomites are very porous and oölitic; others are cherty especially, at base of section
	130	Flower-pot formation Greenish gray shale, minor anhydrite with redbish brown shale, dolomite, and trace of grits
	130	San Angelo formation Fine angular sandstone with reddish cast. Much anhydrite with minor reddish brown and greenish gray shale
	930	Clear Fork group Dolomites, locally oölitic, and minor anhydrite with greenish gray and reddish brown shale
	690	Wichita group Dolomite with trace of anhydrite and greenish gray shale. Trace of black bituminous shale at base

[1] Manuscript received, June 29, 1942.

[2] Geologist, Humble Oil and Refining Company.

Thickness in Feet		
1,400		WOLFCAMP
	340	Porous dolomite with minor chalcedony and chert
	1,060	Fossiliferous limestones, locally porous and cherty. Much very dark gray shale with a few thin beds of fine angular sandstone
		PENNSYLVANIAN
975		CISCO
	400	Gray-black shale with trace of coal
	55	Coarse to fine angular sandstone
	319	Black shale, bituminous. A few thin beds of grits and locally a trace of coal
	86	Black shale, marl, and cherty limestone
	85	Anhydrite containing chalcedony with minor dolomite in lower part
	30	Black shale and black cherty limestone
249		CANYON
		Porous limestone, locally fossiliferous. Minor chert and black shale with trace of angular sandstone in upper part; some green shale in lower part

* The rocks of Leonard age that overlie the Clear Fork group have been designated varyingly as the San Andres group, the El Reno group, the Pease River group, and the "Blaine of Texas." It is unfortunate that so many names have been used for this group of beds, but each has advantages and proponents. The Pease River group is adopted here because its upper and lower limits are easily recognized over much of the east side of the Permian basin. The group includes the beds from the base of the San Angelo sandstone up to the base of the Custer which is 10–30 feet below the base of the magnesian Childress limestone. The group is disconformable at the base and a regional unconformity occurs at the top. The average thickness of the Pease River group is 870 feet. Surface exposures show many cycles of evaporites. which are now greatly condensed by solution. Except for the area in Nolan County, Texas, where redbed clastics are relatively prominent, the group is remarkably uniform in its outcrop expression. The topography is rough with a pronounced development of stair-like escarpments. Vegetation on the Pease River outcrop is notably different from that growing on beds above and below this group.

Since fossils are not present in the anhydrite section, its age may be questioned by some. Fortunately, another well had been drilled $3\frac{1}{2}$ miles due south of No. 2. This well had a very fossiliferous section and with its aid we are able to determine the age of the anhydrite found in No. 2. The south well is the Humble Oil and Refining Company's Matador Land & Cattle Company No. 1 and is located 1,980 feet from the north and east lines of Sec. 26, Block 1, Shock and Arnold Survey, Dickens County, Texas. From an examination of the cuttings from this well it is apparent that gray-black shales and cherty limestones occupy the anhydrite interval. The cherty limestones contain *Triticites beedei*, which is a diagnostic Cisco fossil. Furthermore, in the underlying Canyon the same sequence of *Triticites* zones was present in both wells.

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DISCUSSION

STRATIGRAPHY OF NORTH DAKOTA[1]

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The following discussion of Dr. Virginia Kline's article entitled "Stratigraphy of North Dakota"[4] is presented in an attempt to clarify certain of the geologic interpretations involved. Information obtained from areas adjacent to North Dakota, and other data which were perhaps not available to Dr. Kline at the time of preparation of her paper, are herein summarized.

The writers feel that by the application of currently accepted stratigraphic nomenclature, interpolation, and extrapolation of data from Manitoba, Montana, and South Dakota, and by only the most sparing and critical use of drillers' logs, a clearer picture of North Dakota stratigraphy may be obtained.

This paper represents the ideas and opinions accepted by a group of geologists who have been engaged in surface and subsurface studies in western North Dakota and eastern Montana during the past 4 years. Even though it is recognized that there is great diversity of opinion in stratigraphic correlation, particularly in the formations lying above the Fox Hills, nevertheless the writers believe that the statements which follow can be supported by the latest lithologic and paleontologic evidence.

Surface study, together with a consideration of recent literature regarding the post-Fox Hills formations, indicates the following.

1. "White River" and younger Tertiary sediments are more widely distributed than Dr. Kline indicates.

2. The upper Wasatch is represented by an unnamed unit well developed north of Hebron, North Dakota.

3. The Sentinel Butte is Wasatch in age.

4. The Fort Union formation is represented by three members. These are Tongue River, Cannonball, and Ludlow.

5. The Cannonball and Ludlow are interfingering contemporaneous sediments of early Paleocene age.

6. The Hell Creek is Upper Cretaceous in age.

The stratigraphic classification used by the writers of this discussion, is as follows.

Cenozoic
  Tertiary system
    Oligocene (and Miocene) series
      White River group
    Eocene series
      Wasatch formation
        Unnamed member
        Sentinel Butte member

[1] Manuscript received, May 28, 1942.

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[4] Virginia Kline, "Stratigraphy of North Dakota," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 3 (March, 1942), pp. 336–79.

Paleocene series
Fort Union formation
Tongue River member
Cannonball member—Ludlow member
Mesozoic
Cretaceous system
Upper Cretaceous series
Hell Creek formation
Montana group
Fox Hills formation
Pierre formation
Colorado group
Niobrara formation
Benton formation
Dakota formation
Lower Cretaceous series
Fuson formation
Lakota formation
Jurassic system
Morrison formation
Sundance formation
Triassic system
Spearfish formation
Paleozoic
Permian system
Minnekahta formation
Opeche formation
Pennsylvanian system
Minnelusa formation
Mississippian system
Amsden formation
Big Snowy group
Heath formation
Otter formation
Kibbey formation
Charles formation
Madison group
Mission Canyon formation
Lodgepole formation
Devonian system
Amaranth formation
Manitoban formation
Winnipegosan formation
Elm Point formation
Silurian system
Ordovician system
Big Horn formation
Upper Whitewood formation
Lower Whitewood (Winnipeg) formation
Cambrian system
Pre-Cambrian

TERTIARY

The youngest pre-Pleistocene sediments known in North Dakota are those of Tertiary age described by Earl Douglas.[5] These are grouped under the term "White River" and are considered to be Oligocene in age, although strata of Miocene age may be present. No attempt has been made in North Dakota to separate these strata into units. The known localities of "White River" are more numerous than those given by Dr. Kline. In addition to areas mentioned by her, sediments of this group cap the Blue Buttes in southeastern McKenzie County; the Youngman and Antelope buttes immediately east of Richardton,

[5] Earl Douglas, "Rhinoceroses from the Oligocene and Miocene Deposits of North Dakota and Montana," *Annals Carnegie Museum*, Vol. LV, No. XIV (1906), pp. 256–66.

Stark County; a large area of low flat-topped buttes south and southeast of Lefor, in southern Stark County; the East and West Rainy buttes in northeastern Slope County; and the H. T. and Bullion buttes, as well as Flat Top Butte east of Sentinel Butte. These localities represent remnants of the once extensive fluvial and lacustrine deposits. A widespread unconformity at the base of the "White River" separates this unit from progressively older formations on the south and west in South Dakota and southeastern Montana.

The writers recognize that for many years there has been little agreement and no accepted solution in the "Lance-Laramie problem." In North Dakota the lithology and paleontology of strata formerly classified as "Lance" permit a rather clear-cut subdivision into formations whose stratigraphic positions are quite definite.

The Wasatch formation of Eocene age is represented by two members. The younger is an unnamed light-colored unit, well exposed north of Hebron, North Dakota. The lower member is the Sentinel Butte, a dark bentonitic unit whose type locality is south of the town of Sentinel Butte, North Dakota.

Leonard,[6] in 1911, described a unit composed of light-colored strata which lies above the somber clays of the Sentinel Butte. He did not name the unit or differentiate it from strata herein called Sentinel Butte. The writers have observed these beds north of Hebron, where they were reported by Leonard, and at many other localities in western North Dakota. The maximum observed thickness of the member is 100 feet, but may be greater. Large, bright yellow, calcareous sandstone concretions not exceeding 6 feet in diameter, imbedded in an ashy white matrix, are characteristic of this formation. The concretionary zone is overlain by a bed that appears to contain volcanic ash, and it in turn is overlain by not more than 15 feet of yellow bentonitic clay. In some localities hard purplish gray, bench-forming sandstone lies several feet above the bentonitic layer. Exposures of strata of the same lithologic appearance and similar stratigraphic position, occur west of State Highway No. 8, in T. 146 N., R. 91 W.; along the divide between the Knife and Heart rivers near Taylor; south of Dickinson in the vicinity of Scheffield Post Office, and in the vicinity of Grassy Butte Post Office. These sediments comprise a traceable unit, and represent the youngest pre-Oligocene strata in the region.

In an early paper Leonard[7] described the Sentinel Butte member and placed it in the Fort Union. His discussion follows.

> In Billings County, North Dakota, an upper member of the formation appears in the tops of the higher ridges, divides, and buttes, and resembles somewhat the Lance beds in its dark color and its many brown ferruginous, sandstone concretions. The lower member constitutes the typical yellow and light gray Fort Union and this is the only one present over most of the region. Where both occur, the contrast between the upper and lower members is so well marked and their contact so clearly defined that it can be readily distinguished even at a distance and traced without difficulty, wherever it is exposed.

Hares[8] recognized two members of the Fort Union, the upper or Sentinel Butte, and the lower or Tongue River. He placed the Sentinel Butte only tentatively in the Fort Union.

Thom and Dobbin[9] placed the Sentinel Butte sediments in the Wasatch. Areal geologic studies in the field lead the writers to believe that this classification by Thom and Dobbin is more acceptable. The Sentinel Butte member is considered to be the lower unit of the Wasatch in North Dakota.

[6] A. B. Leonard, "The Cretaceous and Tertiary Formations of Western North Dakota and Eastern Montana," *Jour. Geol.*, Vol. 19 (1911), p. 535.

[7] *Ibid.*, pp. 533–43.

[8] C. J. Hares, "Geology and Lignite Resources of the Marmarth Field, Southwestern North Dakota," *U. S. Geol. Survey Bull. 775* (1928).

[9] W. T. Thom, Jr., and C. E. Dobbin, "Stratigraphy of the Cretaceous-Eocene Transition Beds in Eastern Montana and Dakota," *Bull. Geol. Soc. America*, Vol. 35 (1924), pp. 481–506.

The Sentinel Butte member is characterized by the following features: (1) somber, dark-colored clays, (2) sparse representation of lignite beds, (3) extensive bentonite and bentonitic clays, (4) large numbers of silicified stumps, and silicified plant fragments, ordinarily in well defined layers, and (5) a "mud butte" (Hell Creek) type of topography.

The best exposures of Sentinel Butte are found in the badlands of the Little Missouri River in the vicinity of North Roosevelt Park, McKenzie County, North Dakota. In this locality, near the axis of the Williston Basin syncline, the unit as a whole is flat, and may exceed 550 feet in thickness. Its position in the syncline preserved it from pre-Oligocene erosion. The Sentinel Butte is the surface rock in most of McKenzie, Billings, Dunn, and Stark counties, in eastern Slope County, and in parts of Mercer and Morton counties. It crops out along the Missouri and Little Missouri rivers as far east as Sanish and Elbowoods, and also may be observed in the drainage of the Knife River near Hebron. Dr. Kline's statement that most of this member has been removed by erosion is not supported by the writers' observations in the field.

The Tongue River member of the Paleocene Fort Union formation conformably underlies the Sentinel Butte. A clinker resulting from the burning of a lignite bed marks the contact of the Tongue River and Sentinel Butte members in many places. Numerous clinker beds occur both above and below the contact clinker. Thus, the presence of clinker should not be used indiscriminately as the criterion for separating the two members.

The Tongue River consists of light buff to yellow calcareous sandstones and light gray shales, with numerous lignite beds which range in thickness from a few inches to more than 15 feet. This member of the Fort Union crops out extensively in the badlands of the Little Missouri River from the vicinity of Marmarth, North Dakota, to a point 100 miles north. At the latter locality, the general northeast dip of the strata into the Williston Basin syncline carries the member below river level. The member is exposed over a broad area along the Montana-North Dakota boundary, from northern Slope County at least as far north as the Missouri River. It reappears on the crest of the Nesson anticline in southern Williams County, and is exposed along the Missouri River on the east side of the Williston Basin syncline.

The Cannonball member is present only in the south-central and southwestern part of North Dakota. It consists of buff or greenish marine sandstones and dark gray shales which may attain a thickness of 300 feet. Some of the sandstones are remarkably similar in color, lithology, and topographic expression to sandstones in the Cretaceous Fox Hills formation. The Cannonball merges westward into the non-marine Ludlow member. About 150 species of marine invertebrate fossils are known in the Cannonball. The writers regard the member as Paleocene in age from studies of the invertebrate megafossils by Stanton,[10] and the foraminifera by Fox and Ross.[11] The Cannonball interfingers with and overlies the Ludlow lignitic member which contains a terrestrial Tertiary flora identified by Dorf.[12]

The Ludlow is distinguished from the Cannonball by the presence of numerous lignite beds. The lignite beds, and the buff-colored sands and shales, differentiate the Ludlow member from the underlying Hell Creek. The Ludlow varies in thickness from 40 feet or less near Breien in south-central North Dakota, to 250 feet near Marmarth. Fossil plants from the Ludlow are of Fort Union types and in marked contrast to those of the Hell Creek.

[10] Timothy W. Stanton, "The Fauna of the Cannonball Marine Member of the Lance Formation," *U. S. Geol. Survey Prof. Paper 128* (1920), pp. 1–66.

[11] Stephen Fox and R. J. Ross, "Foraminiferal Evidence for the Midway (Paleocene) Age of the Cannonball Marine Beds in North Dakota," *Bull. Geol. Soc. America*, Vol. 51, No. 12 (1940), p. 1970.

[12] Erling Dorf, "Relationship between Floras and the Type Lance and Fort Union Formations," *ibid.*, Vol. 51 (1940), pp. 223–33.

CRETACEOUS

The Hell Creek is the youngest Cretaceous formation known in North Dakota. In it are found *Ceratops* remains, which the writers accept as proof of the Mesozoic age of these rocks. The Hell Creek consists largely of gray bentonitic sands and shales, within which are lenticular beds of lavender-brown lignitic shale, and rusty brown to purplish black ferruginous concretions. It erodes into somber gray badlands.

Near the mouth of the Cannonball River in south-central North Dakota W. A. Cobban has recently recognized a 30-foot marine bed of greenish gray sand and gray shale near the base of the Hell Creek. It contains *Halymenites*, a recognized criterion for marine origin, pelecypods (*Ostrea glabra*, *Dosiniopsis* sp.?), brachiopods (*Lingula* sp.), and some microfossils. This marine tongue is best developed between Breien and Solen, on the Cannonball River. It extends southward from this area, in a zone about 20 miles wide, at least as far as the South Dakota state line.

The member probably passes into Hell Creek terrestrial deposits not far west. This marine unit overlies 15–25 feet of typical Hell Creek bentonitic shales and sands, which contain dinosaur bones and lignitic shales.

The writers consider the presence of a marine tongue in the Hell Creek terrestrial beds of particular significance. It indicates the persistence of a marine environment from Fox Hills to Cannonball time, east of the main Hell Creek continental area of eastern Montana and western North Dakota.

The thickness of the Hell Creek varies from 575 feet near Marmarth, to less than 100 feet in the Souris River area of north-central North Dakota.

In general, the writers are in agreement with the statements made by Dr. Kline concerning the Fox Hills, Pierre, Niobrara, Benton, Dakota, Fuson, and Lakota.

Although yellow dust which has been proved to be hydrous iron oxide, has been observed in Benton outcrops, the writers have nowhere recognized the occurrence of free sulphur as reported by Dr. Kline. Consequently they believe that the "sulphur" which she mentioned, will be proved to be iron oxide if analyzed.

JURASSIC

The Jurassic is present in the subsurface of North Dakota in the A. R. Jones *et al.* Gehringer No. 1, Sec. 17, T. 161 N., R. 84 W., in the California Company's Kamp No. 1, Sec. 3, T. 154 N., R. 96 W., and in the Prairie Oil and Gas Company's Armstrong No. 1, Sec. 2, T. 140 N., R. 73 W. The maximum Jurassic section is developed in the California's Kamp No. 1, where it is 890 feet (4,635–5,525) thick. The upper 225 feet of this series, identified as Morrison, is composed of gray and green shales, with a few thin, shaly sandstones. The lower 665 feet is assigned to Sundance, and here consists of an upper shaly, glauconitic sandstone member, a medial green shale, and a basal fossiliferous sandy and shaly limestone, which becomes gypsiferous at the base. In the Jones' Gehringer No. 1 the Jurassic encountered at approximately 3,400 feet is thought to be Sundance. Sample control is lacking for the bottom 100 feet of this operation; hence, it is not clear whether all of the Jurassic was penetrated. In the Prairie's Armstrong No. 1, Jurassic is identified, from samples, as occupying the interval from 2,515 to 2,770 feet. The upper 90 feet is assigned to the Morrison, and the lower 165 feet to the Sundance. Good Jurassic sections have been described adjacent to the Black Hills of South Dakota, and have been drilled in the tests on Little Beaver Dome (southern Cedar Creek, or Baker-Glendive anticline), in eastern Montana. In Canada, Jurassic sediments have been identified from wells in southwestern Manitoba. It is evident that in much of western and northern North Dakota, the Jurassic will be found to be present.

TRIASSIC

The Spearfish formation attains a thickness of 925 feet in the California's Kamp No. 1.

This is its greatest known thickness in the Northern Great Plains area. It may be stated as a generality that the Triassic in the Northern Great Plains is readily divisible into two members. The upper member is predominantly composed of red argillaceous sandstone with rounded and frosted quartz grains, and red shales. The lower member consists of arenaceous red to brown shales and evaporites. The division between the Triassic and the Permian might well be placed at the top of the evaporite series.

The subsurface lithology in the Prairie's Armstrong No. 1 suggests to the writers that a part of the redbed section, identified by Dr. Kline as Devonian, may be Triassic in age. As an alternate correlation the writers would include that section from 2,750 to 2,990 feet in the Triassic. In the Black Hills and the tests drilled on Little Beaver Dome, the Spearfish is well developed and attains a thickness of 900 feet.

PERMIAN

In the northern part of the Black Hills, the Permian is represented by the Minnekahta dolomitic limestone, and the red sandstone and shale of the Opeche formation, which have a combined thickness of 150 feet. These formations thin northward, and in the test wells on Little Beaver Dome are 125 feet thick. It is believed by the writers that the Permian may extend a short distance into southwestern North Dakota, but that it is missing in the California's Kamp No. 1.

PENNSYLVANIAN

The Minnelusa formation of Pennsylvanian age averages 450 feet in thickness in the Black Hills of South Dakota. Lithologically the formation is principally white and reddish sandstone, with a subordinate amount of brown and purplish limestones in the lower part. In the wells drilled on Little Beaver Dome, one mile west of the North Dakota boundary, the Minnelusa is a series of sands and dolomitic limestones, and has thinned to 200 feet.

No sediments correlative with the Pennsylvanian could be found by the writers in the California's Kamp No. 1. It is believed that a "wedge-out" of these sediments occurs between Little Beaver Dome and the Nesson anticline. Thus, the writers' opinions are at variance with Dr. Kline's statement that 650 feet of sediments of Permo-Pennsylvanian age are present in the California's Kamp No. 1.

MISSISSIPPIAN

The greatest thickness of Mississippian sediments yet disclosed in the Northern Great Plains area, 3,045 feet, was penetrated in the California's Kamp No. 1. The Mississippian section in this well is represented by black, red, and green shales, sandstones, anhydrites, and limestone. It is believed by the writers that this thick, diversified section is deserving of a more detailed discussion than that presented by Dr. Kline.

In the California's Kamp No. 1, the top of the Mississippian is not clearly defined, but the writers consider it to be at approximately 6,475 feet, and have tentatively assigned the orange, red, and purple dolomites, limestones, and shales from 6,475 to 6,740 feet to the Amsden formation. This is in agreement with the ideas presented by Carmody.[13]

> A lithologic unit is recognized consisting of dolomite, limestone and shale, varying in color from orange through red to purple. . . . This unit fits the thickness and lithologic description given by Scott[14] for the Amsden formation of south central Montana . . . . Sub-surface studies in adjoining areas indicate that this unit is of pre-Pennsylvanian age . . . .

In the Carter Oil Company's Northern Pacific No. 1, Sec. 19, T. 4 N., R. 62 E., eastern

[13] R. A. Carmody, *Guide Book Kansas Geol. Soc., 14th Annual Field Conference* (1940), p. 136.

[14] H. W. Scott, "Some Carboniferous Stratigraphy in Montana and Northwestern Wyoming," *Jour. Geol.*, Vol. 43, No. 8 (1935), pp. 1011–32.

Montana (Little Beaver Dome), this (Amsden) unit is recognized as occupying the interval from 5,880 to 5,985 feet.

Although the term "Amsden" has recently fallen into disfavor because it refers to strata containing Pennsylvanian fauna in Wyoming, and Mississippian fauna in Montana, the writers favor retaining this term because it covers a highly useful cartographic unit that can be mapped on the surface, and identified in well cuttings throughout much of central and eastern Montana and North Dakota. The fauna of the Amsden in the California's Kamp No. 1 indicates that it is Mississippian in age in North Dakota.

Underlying the Amsden in central and eastern Montana is a series of upper Mississippian sediments, called the Big Snowy group by Scott.[15] A near-maximum thickness of these strata is present in the California's Kamp No. 1 (6,740 to 8,125 feet). Although this is the farthest east that this group has been encountered, its presence in deep wells on Little Beaver Dome and near Camp Crook, South Dakota (State Royalty Petroleum's State No. 1, Sec. 35, T. 4 N., R. 1 E., Harding County), indicates that Big Snowy sediments may be expected beneath much, if not all of western North Dakota.

In the type areas of the Big Snowy group (Big Snowy and Little Belt mountains, Montana), Scott[16] has defined the following formations in descending order.

HEATH:—Black petroliferous shales and sandstones.
OTTER:—Gray and green shales intercalated with thin oolitic and fossiliferous limestones.
KIBBEY:—Red sandstone and shale.

Carmody[17] places great significance on the lateral persistence of the Kibbey red sands, and it is possible that these are represented by the interval from 7,030 to 7,315 feet, in the California's Kamp No. 1. Although the writers recognize that there is no unanimity of opinion about the subsurface subdivisions of the Big Snowy group, they consider the interval from 6,745 to 7,030 feet to be correlative with the Heath and Otter formations.

A series consisting of brown shale, salt, anhydrite, and earthy limestone that is not present in the type areas of the Big Snowy occurs between 7,315 and 8,125 feet, in the California's Kamp No. 1, and at a similar position just above the Madison in the deep wells on Little Beaver Dome. The writers consider that this series represents post-Madison, pre-Kibbey sedimentation contemporaneous with erosion or non-deposition farther west. This lowest unit of the Big Snowy was recently called Charles by Seager.[18] The stratigraphic position of this unit was definitely established in the Arro-California's Charles No. 4, Sec. 12, T. 15 N., R. 30 E., Mosby Dome, Montana. The Big Snowy group attains a thickness of 830 feet in the Carter's Northern Pacific No. 1.

Massive limestones typical of the Mission Canyon formation[19] of the Madison group are penetrated below the Charles formation in wells drilled east of the Big Snowy Mountains of central Montana (Arro-California's Charles No. 4, and Prairie Oil and Gas' Westphal No. 1xx, Sec. 26, T. 10 N., R. 39 E., Rosebud County). In addition to the lithologic change from anhydrites and earthy limestones to the massive limestones of the Mission Canyon, porosity and showings of oil and gas are found in many places near the contact which the writers consider to be the top of the Madison group. The faunal evidence for a contact well below the anhydrite is inconclusive.[20] Since "A formation is a

[15] H. W. Scott, *op. cit.*

[16] *Ibid.*

[17] R. A. Carmody, *op. cit.*

[18] O. A. Seager, "Test on Cedar Creek Anticline, Southeastern Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 5 (1942), pp. 861–64.

[19] L. L. Sloss and R. H. Hamblin, "Stratigraphy and Insoluble Residues of Madison Group (Mississippian) of Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 3 (1942), pp. 305–35.

[20] F. W. DeWolf and W. W. West, "Stratigraphic Studies of Baker-Glendive Anticline, Eastern Montana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 4 (1939), p. 461.

lithogenetic unit; it is a sequence of strata which the geologist can map,"[21] this mappable break between the anhydrite unit and the limestone unit is thought to be the best marker for the top of the Madison.

In the California's Kamp No. 1, the top of the Madison is placed at 8,125 feet. The massive limestones between 8,125 and 8,600 feet, and the shaly limestones between 8,600 and 9,540 feet, have the characteristics, respectively, of the Mission Canyon and Lodgepole limestones, of the Madison group, as exposed in the Little Rocky Mountains of north-central Montana.

The black fissile shale encountered in the California's Kamp No. 1 between 9,540 and 9,625 feet marks the base of the Madison group. This shale unit may be traced in outcrops and wells throughout much of central and western Montana and Alberta. At several localities it has yielded Kinderhook conodonts.

DEVONIAN

The presence of Devonian sediments in North Dakota has been definitely established in only a few wells in the northeastern part of the state, and in the California's Kamp No. 1 in the northwestern part. Devonian sediments are not present in the Black Hills, and their presence could not be definitely established in the Carter's Northern Pacific No. 1 on Little Beaver Dome. The nearest exposures are in the Lake Winnipeg area of Manitoba, and in the Little Rocky Mountains of north-central Montana. It is assumed that the Devonian in North Dakota is similar to that described at the outcrops and in wells in Manitoba.

The Devonian of Manitoba may be divided into four units. The uppermost, the Amaranth, is predominantly composed of gypsum and limestone, and attains a thickness of 260 feet.[22] The other units in descending order are: the Manitoban limestone, chiefly a non-magnesian light gray limestone, 190–200 feet in thickness; the Winnipegosan dolomite, which is white or cream-colored, and varies in thickness from 170 to 200 feet; and the Elm Point limestone, a gray argillaceous limestone having a thickness of 30–60 feet. Subdivision of the three lower formations is based on fossil evidence.[23]

In the California's Kamp No. 1, the top of the Devonian is placed at the base of the black Kinderhook shale (Mississippian), at 9,625 feet. The writers are in agreement that the well probably was in Devonian sediments at the total depth of 10,281 feet.

There is no good stratigraphic or faunal evidence to support the presence or absence of Devonian in central North Dakota. It is assumed that sediments of this age will be found in the subsurface throughout the greatest part of North Dakota, from the fact that there is a considerable thickness in northwestern North Dakota and in the Lake Winnipeg region.

SILURIAN

No Silurian is known in Montana, Wyoming, North Dakota, or South Dakota in outcrop sections. It has not been identified in wells in eastern Montana, South Dakota, or central or western North Dakota. A good Silurian section which may be correlated with the Stonewall, Manitoba, quarry outcrop, was drilled in the Commonwealth Petroleum Ltd., Manitou No. 2, LSD Sec. 26, T. 2 N., R. 9 W., 1st Meridian, Manitoba. The writers recognize the probability that the Silurian extends a short distance into northeastern North Dakota. However, the interpretation of well samples does not indicate any large areal extent of Silurian sediments in North Dakota.

[21] H. G. Schenck *et al.*, "Stratigraphic Nomenclature," *ibid.*, Vol. 25, No. 12 (1941), p. 2201.

[22] G. M. Brownell, "The Amaranth Gypsum Deposit," *Bull. Canadian Inst. Min. Met. 233* (1931), pp. 1048–68.

[23] E. M. Kindle, "The Silurian and Devonian Section of Western Manitoba," *Canada Geol. Survey Summ. Rept.* (1914), pp. 247–61.

ORDOVICIAN

On the basis of lithologic sequence, the writers believe certain strata which Dr. Kline doubtfully assigned to the Cambrian, should be properly considered Ordovician in age. Wherever information is available in eastern North Dakota, a sequence of sandstones overlain by shales is found at the base of the Paleozoic section.

In Manitoba this sequence is represented by the Winnipeg formation of recognized Ordovician age, which lies directly on the pre-Cambrian. It consists of a basal sandstone containing thin, greenish shale partings. The shale becomes more abundant higher in the section, and grades into well bedded green shale which contains a middle Ordovician fauna. The basal sandstone varies in thickness, probably due to the irregularity of the floor upon which it was deposited.[24] In the Commonwealth's Manitou No. 2, the basal sandstone is 2 feet thick[25] (samples in Borings Laboratory, Canadian Geological Survey, Ottawa, Ontario, Canada). It is overlain by a series of dull green shales, with two thin strata of arkosic sandstone and quartz sand near the base. In the Grafton artesian well, Sec. 13, T. 156 N., R. 53 W., Walsh County, North Dakota, 104 miles southeast of the Commonwealth's Manitou No. 2, 26 feet of sandstone and red sandy shale rests on pre-Cambrian granite. This is overlain by 135 feet of greenish blue shale and gray "slate." In the water well at Hamilton, Pembina County, North Dakota (Sec. 35, T. 162 N., R. 53 W.), 30 miles north of Grafton, the drillers' log shows 130 feet of blue shale overlying 5 feet of white sandstone which rests on "Blue granite." In the Glenfield Oil Company's well, Sec. 18, T. 146 N., R. 62 W., Foster County, North Dakota, the lowermost Paleozoic is a sandstone series overlain by dull gray-green and dull chocolate-brown shale. The drillers' log for the Prairie's Armstrong No. 1 indicates that sandstone at the bottom of the hole is overlain by gray and brown shales. In the Carter's Northern Pacific No. 1, a sandstone, overlain by green shale, which contains Ordovician graptolites and conodonts, rests on strata with a Cambrian fauna.

The Carter's Northern Pacific No. 1 penetrated 1,590 feet of Ordovician sediments which may be divided into three units. The uppermost of these (7,845–8,300) is a series of earthy and crystalline dolomites with some maroon shale seams in the lower third. The basal 18 feet is green calcareous shale with variegated maroon and green at the top. This unit is highly fossiliferous. The identification of a representative upper Ordovician fauna (*Rhynchotrema* cf. *capax*, *Dalmanella* cf. *meeki*, *Strophomena* cf. *planumbona*, *et cetera*) by members of the Carter staff was confirmed by L. L. Sloss. It is suggested that this upper unit is the eastern representative of the Big Horn dolomite. The middle division (8,300–8,830 feet) is principally gray massive granular crystalline limestone which the writers correlate with the upper Whitewood of the Black Hills. The lowermost division (8,830–9,435 feet) consists of interbedded green sandy shale, sandy shaly limestone, and sandstone, with the percentage of sandstone increasing toward the base. Conodonts, identified from green shales by Dr. C. R. Stauffer,[26] place the age as middle Ordovician. This suggests probable age equivalence with the Winnipeg sandstone and the lower Whitewood of the Black Hills.[27]

There is no reason to doubt that a considerable thickness of Ordovician will be found to be present in the subsurface in much of North Dakota.

[24] G. S. Hume, "Oil and Gas in Western Canada," *Geol. Survey Canada Econ. Geol. Ser.* 5 (1933), p. 256.

[25] J. C. Sproule, personal communication (1940).

[26] C. R. Stauffer, personal communication (1941).

[27] W. M. Furnish, E. J. Barragy, and A. K. Miller, "Ordovician Fossils from Upper Part of Type Section of Deadwood Formation, South Dakota," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 10 (1936), pp. 1329–41.

CAMBRIAN

The writers believe that the Cambrian is absent in eastern North Dakota, and that strata which Dr. Kline doubtfully assigned to the Cambrian are Ordovician in age.

In the Montana-North Dakota area, the thickest Cambrian sediments are found in the region of the Cordilleran geosyncline where the Cambrian exceeds 2,200 feet.[28] In the Little Rocky Mountain area of north-central Montana the Cambrian has thinned to approximately 800 feet,[29] where it is represented by a glauconitic and sandy dolomitic limestone, flat pebble conglomerate, and intercalated green shale which grades downward through several hundred feet of green fissile shale, into the basal (Flathead) sandstone. In the northern part of the Black Hills, the dolomitic limestone and flat pebble conglomerates, with intercalated green shales of the Deadwood formation, grade downward to glauconitic and ferruginous sandstones resting on a basal ferruginous conglomerate. Near the southwestern boundary of North Dakota the Cambrian is represented by only 219 feet of sediments in the Carter's Northern Pacific No. 1. There the Cambrian consists of interbedded green shale and dolomite, overlying a basal glauconitic sandstone. Its age is determined by the presence of Cambrian linguloid brachiopods.

Evidence indicates that the Cambrian thins progressively eastward, and if present in North Dakota, is restricted to the western part of the state.

PRE-CAMBRIAN

The Proterozoic (?) system in the area on the south and east (of North Dakota) consists of granites, granite gneiss, schists, and quartzites. Archeozoic biotite granite, medium to coarse in texture, is extensively exposed along the southern part of Big Stone Lake in Grant County, North Dakota. Other pre-Cambrian exposures in adjacent parts of Minnesota are classed as biotite-granite gneiss. The pre-Cambrian of the Black Hills consists of a complex series of conglomerates, arkoses, quartzitic schists, quartzites, and graywackes invaded by granites and pegmatites. The pre-Cambrian of western Manitoba, as revealed by well samples, consists of granites, gneisses, and schists.

The Carter's Northern Pacific No. 1 encountered pre-Cambrian amphibolites at the depth of 9,654 feet. This is similar to some of the amphibolites in the northern Black Hills.[30] The few wells listed by Dr. Kline in the eastern part of the state, others in adjacent counties of Minnesota,[31] and the foregoing, constitute the extent of our knowledge about the pre-Cambrian.

This discussion was prepared for the purpose of supplementing Dr. Kline's paper "Stratigraphy of North Dakota." It is also intended to demonstrate that diverse opinions are held on the interpretation of the stratigraphy of this state. It recognizes the fact that many problems exist, and that much research and additional information will be necessary before a solution satisfactory to all may be reached.

[28] Charles Deiss, "Cambrian Stratigraphy and Trilobites of Northwestern Montana," *Geol. Soc. America Spec. Paper 18* (1939).

[29] Frank Reeves, "Geology and Possible Oil and Gas Resources of the Faulted Area South of the Bearpaw Mountains, Montana," *U. S. Geol. Survey Bull. 751 C* (1925), p. 75.

[30] James A. Noble, personal communication (1941).

[31] Ira S. Allison, "The Geology and Water Resources of Northwestern Minnesota," *Minnesota Geol. Survey Bull. 22* (1932).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 26, NO. 8 (AUGUST, 1942), PP. 1424-1429

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and available, for loan, to members and associates.

GEOLOGY OF HOLMES AND WASHINGTON COUNTIES, FLORIDA, BY ROBERT O. VERNON

REVIEW BY ROBERT B. CAMPBELL[1]
Tampa, Florida

"Geology of Holmes and Washington Counties, Florida," by Robert O. Vernon. *Florida Geol. Survey Bull. 21* (Tallahassee, January, 1942). 161 pp., 2 pls. (in pocket), 8 tables, 20 figs.

This bulletin by Dr. Vernon is the first of a series of county reports planned by the Florida Geological Survey and proves to be an auspicious beginning. After a brief abstract and an introduction which discusses location, maps, some notes on Indian occupation, and some on land utilization, Vernon launches into a description of the physiography of the area which he divides into a "River Valley Province" and a "Coastal Plains Province." The first lies along the main drainage system of the Choctawhatchee River, and its sediments consist of Recent and terrace alluvium and Tertiary deposits arranged in four terraces. The "Coastal Plains Province" he divides into five definite levels though he felt it the part of caution not to use terrace names employed by other writers on the subject beyond the area of his own report. He made no attempt to correlate the components of the two groups. However, Cooke, who had previously discussed Florida marine terraces,[2] spent two weeks in the field with Vernon, and correlated five of his seven coastal terraces with those reported in the present bulletin, this despite the fact that Vernon gives the age of these features as "Pliocene and Pleistocene," while Cooke regards them as all post-glacial. Vernon recognizes no evidence of tilting in western Florida, thus concurring with Cooke, but at variance with Fisk[3] and Russell[4] for their Louisiana work, and Leverett,[5] who published on the Pensacola Terrace. Nevertheless, Vernon's report on the facts observable in these two counties is a contribution welcomed by adherents of both theories of explanation.

A table of formations on page 34 epitomizes the results of Vernon's stratigraphic studies in these two counties. No new formations are named, though rocks formerly mapped as Tampa or Ocala have now been assigned to the Suwannee. Vernon maps twelve units ranging in age from Eocene to Recent, the Marianna limestone (Oligocene) being mapped for the first time west of the Choctawhatchee River. His work on the Miocene demonstrates that faunal units, heretofore regarded as representing different time intervals, are actually time equivalents differing only in facies.

[1] Petroleum geologist, 1321 Memorial Highway. Manuscript received, June 8, 1942.

[2] C. Wythe Cooke, "Scenery of Florida," *Florida Geol. Survey Bull. 17* (Tallahassee, 1939).

[3] H. N. Fisk, "Geology of Grant and LaSalle Parishes," Dept. of Conservation, *Louisiana Geol. Survey Bull. 10* (1938). 246 pp.

———, "Depositional Terrace Slopes in Louisiana," *Jour. Geomorphology*, Vol. 2 (1940), pp. 181–200.

[4] Richard Joel Russell, "Quaternary History of Louisiana," *Bull. Geol. Soc. America*, Vol. 51 (1940), pp. 1199–1234.

[5] Frank Leverett, "The Pensacola Terrace and Associated Beaches and Bars of Florida," *Florida Geol. Survey Bull. 7* (Tallahassee, July, 1931).

As an introduction to the description of each formation, Vernon has written a "Historical Summary" which furnishes a lucid account of the vagrancies of various formations throughout the Cenozoic column, and adds much to the reader's geologic understanding, not only of this particular area, but generally of western Florida as well.

A few pages are taken with brief notes on economic deposits, including a discussion of oil possibilities. On this latter subject Vernon quotes a few rather vague comments pro and con, but he himself is obviously not impressed with the petroleum possibilities of his area. His attitude, however, seems based on his questioning of the quality and validity of the evidence adduced to prove local surface structure. He does not consider subsurface conditions at all in this connection. Parenthetically, it might be noted that one item contributes to the work of the structural geologist. Vernon reports that the Ocala limestone occurs at 98 feet below sea-level in a well located in Sec. 24, T. 3 N., R. 18 W., Holmes County. Ocala points are scarce in west Florida, so each new contribution is eagerly awaited. The point here furnished does little more than confirm the normal dip as earlier mapped.

Numerous faunal check lists, attractive photographs, and cross sections add much to the usefulness of the bulletin, though the clearly drawn cross sections have been so reduced in size for the format used as to be difficult to read. A geologic map for each of the two counties is included in a folder. Well worked out and carefully drawn, they are nevertheless very difficult to read. Reasons for this are: (1) details of terrace deposits obscure the mapping of the earlier Tertiaries and (2) the map is made in only two colors, black depicting both drainage and culture, and a red stippled or hachured pattern representing the various formations and terrace deposits. Possibly means can be found for future issues of this series to enjoy more of the lithographer's art.

STRATIGRAPHIC AND PALEONTOLOGIC STUDIES OF WELLS IN FLORIDA, BY W. STORRS COLE

REVIEW BY ROBERT B. CAMPBELL[1]
Tampa, Florida

"Stratigraphic and Paleontologic Studies of Wells in Florida," by W. Storrs Cole. *Florida Geol. Survey Bull. 19* (Tallahassee, August 1, 1941).

This bulletin on paleontology and stratigraphy is the second of a series of such studies by Dr. Cole on the subsurface of Florida as revealed by well cuttings, the first[2] reporting on a 5,022-foot well in Jackson County and a 1,035-foot well in Gulf County, the present bulletin describing cores and cuttings from a 10,006-foot well in the Everglades (Monroe County), and a 520-foot well near Lakeland in Polk County. The study of this last well revealed that the bit was in middle Eocene when the well was finished, having penetrated 250 feet of Miocene (Tampa and Hawthorne formations) and 120 feet of Ocala (upper Eocene) limestone. From the cuttings, Cole described five new Eocene species of Foraminifera.

From the 10,006-foot well in the Everglades (Peninsular Oil and Refining Company's Cory No. 1), Cole has described eight new species and one variety, doing a needed service with a number of Foraminifera hitherto only noted by generic names, frequently questionably and occasionally incorrectly. Perhaps one change should be noted here. A foram referred to as *Coskinolina cookei* is in this bulletin described as *Dictyoconus cookei*, and it occurs in a zone below the Ocala and again in the Suwannee (Oligocene) limestone above.

[1] Petroleum geologist, 1321 Memorial Highway. Manuscript received, June 8, 1942.

[2] W. Storrs Cole, "Stratigraphy and Micropaleontology of Two Deep Wells in Florida," *Florida Geol. Survey Bull. 16* (Tallahassee, October 31, 1938).

Cole dismisses the Suwannee occurrence as reworked fossils, but other paleontologists working on the problem insist that there is no evidence of reworking and that this represents a recurrent species. In the laboratories the argument has become ardent and, by way of explanation, Cole has included in his paper correspondence between him and Sidney A. Stubbs, assistant State geologist, who takes the latter view.

The assignment of the previously designated *Coskinolina* to *Dictyoconus* brings about a change in naming zones of the Eocene section: the zone referred to previously as the "*Dictyoconus* zone" must become "*Dictyoconus gunteri* zone," and the "*Coskinolina* zone" must be now referred to as the "*Dictyoconus cookei* zone." Some unpublished work avoids this last difficulty by referring to the zone as the *Lituonella*, after another nearly equally common fossil.

Cole's division of the section is as follows.

		Depth in Feet
Pliocene	Caloosahatchie formation	90
Miocene	Hawthorne formation	590
	Tampa limestone	900
Oligocene		1,220
Eocene	Ocala limestone	1,340
	Dictyoconus cookei zone	2,050
	Dictyoconus gunteri zone	3,350
	Borelis zone	5,760
Upper Cretaceous		

The Upper Cretaceous, according to Cole, may be as high as 3,350 feet, but he does not find diagnostic fossils until a depth of 5,760 feet is reached. Cole discusses this reviewer's assignment of the lowermost 2,000 feet penetrated in the well to the Middle Cretaceous[3] and does not accept it. The reason seems to be his unwillingness to base any stratigraphic point on evidence other than a species determination. His statement on page 3 that "paleontologic evidence is virtually lacking below 2,000 feet," and on page 17 his reference to the occurrence, in these bulletins, of *Borelis* sp. and *Lepidorbitoides* sp. indicate this, though he admits a Cretaceous age for the chalk containing *Lepidorbitoides*.

But these columns are no place for cavil. In this series of bulletins, Dr. Cole and the Florida Geological Survey are making valuable contributions to science and furnishing practical aid to structural geologists working in the state.

[3] Robert B. Campbell, "Deep Test in Florida Everglades," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), pp. 1713–14.
———, "Outline of the Geological History of Peninsular Florida," *Proc. Florida Acad. Sci.*, Vol. 4 (1939), pp. 96–97.

STRATIGRAPHIC AND PALEONTOLOGIC STUDIES OF WELLS IN FLORIDA—NO. 2, BY W. STORRS COLE

REVIEW BY ROBERT B. CAMPBELL[1]
Tampa, Florida

"Stratigraphic and Paleontologic Studies of Wells in Florida—No. 2," by W. Storrs Cole. *Florida Geol. Survey Bull. 20* (Tallahassee, April 1, 1942). 57 pp., 4 figs., 16 pls.

This paper, the third of a series (see previous review), describes the geologic column on the west side of the Floridan peninsula and includes the description of fifteen new species of Foraminifera. The two wells yielding the samples are the Suwannee Petroleum Corporation's Sholtz No. 1, drilled during the years 1926 to 1929, and the Florida Oil Discovery Company's Cedar Keys No. 2, drilled 1,600 feet north of the Sholtz well, finally abandoned early this year.

[1] Petroleum geologist, 1321 Memorial Highway. Manuscript received, June 8, 1942.

The *Dictyoconus*, formerly called *D. gunteri*, has in this bulletin been assigned to *D. americanus* Cushman which causes another zone name change. Cole indicates the following section for the two wells.

	Depth in Feet	
	Sholtz 1	*Cedar Keys 2*
Ocala limestone	145	No samples to 400
Dictyoconus cookei zone	840	
Dictyoconus americanus zone	1,930	2,051
	No samples 2,090	
Borelis gunteri zone	2,250	2,554
	No samples 2,807	
Selma formation	3,680	3,697
Eutaw formation	4,010 T.D.	4,270
Tuscaloosa formation		5,266 T.D.

Dr. Cole's interest and industry in this work are doing much to forward the study of Florida's past, both biotic and geologic. Workers in the southeastern states look forward to future contributions for the same area.

A suggestion to Dr. Cole in the matter of naming new Foraminifera described from Florida wells may not be amiss. In the three bulletins of this series (Nos. 16, 19, and 20), he has named twenty-five new species, about half of which are termed *gunteri* or *floridana*. Inasmuch as these names have been generously used by other workers in the past, the suggestion is offered that specific names be drawn from other sources, names that may serve better as mnemonic pegs. Florida's history and geography offer much, Seminole words being common. Though prosaic enough in translation, they are distinctive, poetic and (at least within the requirements of international nomenclature) pronounceable.

THE ECOLOGY AND GEOLOGIC ROLE OF MANGROVES IN FLORIDA, BY JOHN H. DAVIS, JR.

REVIEW BY ROBERT B. CAMPBELL[1]
Tampa, Florida

"The Ecology and Geologic Role of Mangroves in Florida," by John H. Davis, Jr. Papers from *Tortugas Laboratory*, Vol. XXXII. Preprinted from *Carnegie Inst. of Washington Pub. 517* (September 27, 1940), pp. 303–412.

In this paper Dr. Davis has given a clear picture of the details of land accretion through the agency of mangrove growth along the tropical marine littoral. Dr. Davis' studies included a small area on the east coast near Cape Canaveral and another on the west coast extending north and south of Tampa Bay, but the most extensive and probably the most fruitful studies were in the southern part of the state, the Key region from Dry Tortugas to Biscayne Bay, Florida Bay, and the Ten Thousand Islands. This last is the largest mangrove region in Florida, and one of the best developed in the world. Some of the red mangroves here attain to a height of 100 feet.

Three-quarters of the paper (pp. 307–87) discusses the several genera and their associates together with such environmental factors as salinity, soils and substrata, tides, water level, aeration, drainage, and climate. Dispersal and establishment factors are also considered, the entire study crystallizing into a figure (Fig. 3, p. 324) of typical development sequence from pioneer red mangroves on the bars and submerged shoals succeeded by the mature red mangroves along the high-tide level. In the lagoonal area in the lee of these, the black mangrove or honey mangrove develops. Next, behind a rank of twisted

[1] Petroleum geologist, 1321 Memorial Highway. Manuscript received, June 8, 1942.

and knotty buttonwoods, is developed the typical tropical forest. Such a sequence indicates the typical development of the soil profile which consists of: (1) the basic soil of marine origin on which the pioneer red mangrove started; (2) an organic soil varying from fibrous peat to muck deposited in the outer swamps and lagoonal area in and behind the red mangroves; and (3) a top layer of marl or sand washed in over the peat and muck area.

The last part of the paper (pp. 383–412) is concerned with both areal and vertical land accretions. Comparison of recent surveys by the United States Coast and Geodetic Survey and Army Air Service with maps of earlier surveys shows many evidences of new and enlarged lands. Considering new and mature swamp areas as land, Dr. Davis estimates that the recently formed land in the region from Florida Bay to Biscayne Bay would amount to more than 1,000 acres.

The gains to the land area mentioned are not startling, but the depths of the peat deposits may be of help in interpreting past relative changes in sea-level. The depth of many of these greatly exceeds tidal range, and the deepest of these may be explained by assuming a gradual rise in relative sea-level either through glacial control or land subsidence. Further studies of these peat deposits may indicate differential subsidence of various parts of the coast. The data given in this paper indicate that such subsidence only occurred in the southwest region recording no peat beds greater than tidal range—thus no evidence of subsidence—in the Cape Canaveral region. All other conditions being equal, this would be interpreted as indicating a slight tilting of the Floridan peninsula toward the west since the last glacial stage. This is a problem currently engaging the attention of geologists in Florida.

RECENT PUBLICATIONS

ALASKA

"Tertiary Deposits of the Eagle-Circle District, Alaska," by J. B. Mertie, Jr. *U. S. Geol. Survey Bull. 917-D* (May, 1942), pp. 213–64, Pl. 8, Fig. 7. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.15.

"Geology of the Gerstle River District, Alaska, with a Report on the Black Rapids Glacier," by F. H. Moffit. *Ibid., 926-B*, pp. 107–60, Pls. 2–11, Figs. 4–6. Price, $0.35.

CALIFORNIA

*"Mineral Resources of Humboldt County," by Chas. V. Averill. *California Jour. Mines and Geol.*, Vol. 37, No. 4 (San Francisco, October, 1941), pp. 499–528; 7 figs.

*"West Montebello Oil Field and Application of the State Gas Law," by H. P. Stolz. *California Oil Fields*, Vol. 25, July, 1939, June, 1940 (San Francisco, July, 1942), pp. 5–23; 3 figs., 5 pls.

*"Significance of Lepidocyclina (Lepidocyclina) californica, New Species, in the Vaqueros Formation (Tertiary), California," by Hubert G. Schenck and T. S. Childs, Jr. *Stanford Univ. Pub., Univ. Ser., Geol. Sci.*, Vol. 3, No. 2 (Stanford Univ. Press, 1942). 60 pp., 4 pls., 7 figs.

GENERAL

*"Integration of Geology, Physics, and Chemistry for the Solution of Earth Problems." Report of geophysics education committee of Mineral Industry Education Division. *Amer. Inst. Min. Met. Eng. Tech. Pub. 1483* (29 West 29th Street, New York, July, 1942). 20 pp.

*"Geophysical Education," by Donald C. Bradford. *Amer. Inst. Min. Met. Eng. Tech. Pub. 1488* (July, 1942). 9 pp.

*"Pleistocene Chronology," by A. J. Bull. *Proc. Geol. Assoc.* (London, April 24, 1942), pp. 1–45; 1 pl.

**Plane Table Notes and Notebook*, by Kenneth K. Landes. *Notes:* 15 pp., 4×6 inches. *Notebook:* abbreviated rules on stiff paper cover, ruled sheets for vertical angle notes and stadia traverse notes, 4.875×7.75 inches, spiral binding. George Wahr, publisher, Ann Arbor, Michigan (1942). Price, $1.00.

"Geology and Biology of North Atlantic Deep-Sea Cores between Newfoundland and Ireland, Part 5, Mollusca," by H. A. Rehder; "Part 6, Echinodermata," by A. H. Clark; "Part 7, Miscellaneous Fossils and Significance of Faunal Distribution," by L. G. Henbest. *U. S. Geol. Survey Prof. Paper 196-D* (May, 1942), pp. i-xv, 107–33, Pls. 1–2, 20–23, Fig. 1. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.30.

*"Terebratuloid Brachiopoda of the Silurian and Devonian," by Preston E. Cloud, Jr. *Geol. Soc. America Spec. Paper 38* (New York, June 10, 1942), 182 pp., 26 pls., 17 figs., 3 tables.

*"Passing of Cretacic Colorado Group," by Charles Rollin Keyes. *Pan-Amer. Geol.*, Vol. 77, No. 5 (Des Moines, Iowa, June, 1942), pp. 327–39; 3 figs.

"Geophysics in War," by C. A. Heiland. *Colorado School of Mines Quar.*, Vol. 37, No. 1 (Golden, 1942). 85 pp., illus. Price, $1.00.

The Beginnings of the Petroleum Industry: Sources and Bibliography, by Paul H. Giddens. 195 pp., illus. Published by Pennsylvania Historical Commission, Harrisburg, Pennsylvania (1942). Price, $0.50.

*"Review of Ultimate Recovery Factors and Methods of Estimating," by S. F. Shaw. *Oil Weekly*, Vol. 106, No. 6 (July 13, 1942), pp. 16–26; 1 fig., 7 tables.

*"Foraminifera of Submarine Cores from the Continental Slope, Part 2," by Fred B. Phleger, Jr. *Bull. Geol. Soc. America*, Vol. 53, No. 7 (New York, July 1, 1942), pp. 1073–98; 3 pls., 6 figs.

ILLINOIS

*"Outlines of Illinois Geology," by Charles Keyes. *Pan-Amer. Geol.*, Vol. 77, No. 5 (Des Moines, Iowa, June, 1942), pp. 351–70; 4 figs.

INDIANA

*"Middle Devonian Stratigraphy of Indiana," by Guy Campbell. *Bull. Geol. Soc. America*, Vol. 53, No. 7 (New York, July 1, 1942), pp. 1055–72; 2 figs.

PENNSYLVANIA

*"Guidebook to the Geology of the Pennsylvania Turnpike," by A. B. Cleaves and George H. Ashley. *Pennsylvania Topog. and Geol. Survey Bull. G 20* (Harrisburg, 1942). 38 pp., 14 pls., 23 figs.

TEXAS

*"Source of Beach and River Sands on Gulf Coast of Texas," by Fred M. Bullard. *Bull. Geol. Soc. America*, Vol. 53, No. 7 (New York, July 1, 1942), pp. 1021–44; 3 pls., 7 figs.

TURKEY

*"The Microfauna of the Basal Eocene and Upper Cretaceous Section of Ramandag Well No. 2, Southeastern Turkey," by Mehlika Izgi and S. V. Tromp. *Maden Tetkik ve Arama Entitüsü Mecmuasi*, Sene 7, Sayi 1/26 (Ankara, 1942), pp. 113–20 in Turkish, 121–25 in English, 1 faunal chart.

*"Paleocene Fauna of the Region of Sivrihisar-Polati," by Lutfiye Erünal. *Ibid.*, pp. 126–29 in Turkish, pp. 129–32 in French, 1 sketch map and 1 plate of fossils.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 26, NO. 8 (AUGUST, 1942), PP. 1430-1433

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 26, NO. 8 (AUGUST, 1942), P. 1434

Memorial

WILLIAM CLAUDE McGLOTHLIN

(1895–1942)

The American Association of Petroleum Geologists and the oil fraternity mourn the passing of William Claude McGlothlin at Corsicana, Texas, June 1, 1942. His death followed an extended illness which had kept him confined in the local hospital for several months.

Mr. McGlothlin was born in Dallas, Texas, March 26, 1895. He attended the University of Oklahoma from 1914 to 1918, where he received an A.B. degree in geology. He was a member of Phi Gamma Delta fraternity and played football as a regular lineman for his Alma Mater in 1915–1916–1917.

Mr. McGlothlin was married to Roma Lemetha Darling in Ranger, Texas, June 21, 1919.

He was employed during the summer of 1917 by the Empire Gas and Fuel Company of Bartlesville, Oklahoma. This first experience in oil so impressed him that he decided to make the oil business his life's work, and this desire was granted him to the end.

He was employed in the geological department of the Sinclair Oil Company from 1919 to 1921. In 1921 he was employed as geologist for the Gulf Production Company where he remained until 1931. During his employment with the Gulf Production Company he was located at Corsicana and Tyler, Texas, as zone geologist, where, during the boom days of the Mexia, Powell, and East Texas fields, he met and made many of his numerous friends.

From 1931 until his death he was engaged in business as consulting geologist and independent oil operator in Corsicana, Texas.

He was better known as "Big Mack" to all of his friends and it can truly be said that he had no enemies. Big, generous, good-natured, with vision and an abundance of optimism, is the way one would describe him. All of these qualities contributed to his success and only his untimely end prevented him from achieving his high goal.

He became an active member of the A.A.P.G., August, 1931, being sponsored by A. R. Denison, H. E. Minor, and D. J. Edson. He was a thirty-second degree Mason and a member of Hella Temple, Dallas; a Rotarian; a member of the Third Avenue Presbyterian Church, Corsicana, Texas; and head of an organization of the Boy Scouts of America. He was also a contributor to the publications of the A.A.P.G.

"Big Mack" was a student of subsurface geology and contributed much to the oil development of East Texas. His determination to back his judgment led to the discovery of the Pittsburg field in Camp County, Texas.

He is survived by his wife; two daughters, Mrs. William W. Hamilton and Mrs. Walter J. Hillabrant; a son, William C. McGlothlin, Jr., cadet in the United States Military Academy, West Point; a grandson, William McGlothlin Hamilton; his mother, Mrs. J. T. McGlothlin; five sisters, Mrs. L. H. Osborne, Mrs. A. E. Wiseman, Mrs. Ray McBrian, Mrs. A. E. Andrews, and Miss Ruby McGlothlin; and a brother, John Thomas McGlothlin, Jr.

His passing marks another loss to the oil fraternity; a man of sincerity, genuineness of character, and possessed with a pioneering spirit so essential to the industry.

H. E. MINOR

HOUSTON, TEXAS
June, 1942

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 26, NO. 8 (AUGUST, 1942), PP. 1435-1440

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

LESLIE C. CASE, of the Gulf Oil Corporation, Tulsa, presented a paper on "Chemistry in Discovery and Production of Petroleum" at a research conference of the American Association for the Advancement of Science, at Gibson Island, Maryland, June 18.

JOHN R. SUMAN, vice-president of the Humble Oil and Refining Company, Houston, recently received the honorary degree of Doctor of Engineering from the South Dakota School of Mines.

REGINALD A. DALY, Sturgis Hooper professor of geology at Harvard, was given the honorary degree of Doctor of Science at the 300th commencement of the university.

ELIOT BLACKWELDER, of Stanford University, California, and FRANK W. DEWOLF, of the University of Illinois, Urbana, received personal honor citations from the College Division of the University of Chicago Alumni Association, June 13.

E. DEGOLYER, a past-president of the Association, has been appointed assistant deputy coördinator in the Office of the Petroleum Coördinator for Defense, at Washington, D. C.

NICHOLAS A. ROSE, geologist with the ground water division of the United States Geological Survey, recently presented a paper entitled "The Ground-Water Resources of the Houston District, Texas," before the Houston Geological Society at Houston, Texas.

Officers for the current year for the Panhandle Geological Society are as follows: president, EARLE N. ARMSTRONG, Shamrock Oil and Gas Company, Amarillo, Texas; vice-president, JOHN S. VAN SANT, Huber Corporation, Borger, Texas; secretary-treasurer, FRED A. DEVIN, The Pure Oil Company, P. O. Box 2127, Amarillo, Texas.

HARRY W. ANISGARD is with the Texas Petroleum Company, Ltd., at Apartado 267, Caracas, Venezuela.

President AURIN was in Pittsburgh, Washington, D. C., and New York City recently conferring with members of the Association.

Past-president EDGAR W. OWEN, with the Lew H. Wentz Oil Division at San Antonio, Texas, since 1927, has been commissioned as captain and reported for duty in June to the Air Intelligence School. He has been at Miami Beach, Florida, and is now at Harrisburg, Pennsylvania.

LYMAN TOULMIN, JR., has left the department of geology, Texas Agricultural and Mechanical College, College Station, Texas, and is with the Geological Survey of Alabama, University, Alabama.

MAREE CUMMINGS, efficient and faithful office secretary at A.A.P.G. headquarters since 1929, died at Tulsa, Oklahoma, June 25, following an appendectomy. Burial was at Shawnee, Oklahoma.

A. H. SUTTON and his assistant, RAYMOND C. GUTSCHICK, both of the department of geology and geography at the University of Illinois, Urbana, are engaged, during the summer, in exploratory work for fluorite for the Aluminum Ore Company, Rosiclare, Illinois.

JOHN FITTS, geologist of southern Oklahoma, for whom the Fitts pool was named, died at Sulphur, Oklahoma, June 30, at the age of 62 years.

FRANK COLLINS BAKER, curator of the Museum of Natural History, University of Illinois, Urbana, Illinois, since 1918, died May 7.

The 55th annual meeting of the Geological Society of America will be held in Ottawa, Canada, December 29–31, in connection with the celebration of the 100th anniversary of the founding of the Geological Survey of Canada. The Chateau Laurier is to be the headquarters hotel, and the scientific sessions will be held there. The Paleontological Society, the Mineralogical Society of America, the Society of Economic Geologists, and the Society of Vertebrate Paleontology will schedule their meetings in connection with the G.S.A. Other information may be obtained from secretary H. R. ALDRICH, 419 West 117th Street, New York City.

The Petroleum Division of the American Institute of Mining and Metallurgical Engineers will meet at the Ambassador Hotel, Los Angeles, California, October 14–16, and at Austin, Texas, October 29–31.

The 23d annual meeting of the American Petroleum Institute will be held at the Palmer House, Chicago, November 9–13.

W. E. BIVENS, JR., recently geologist and engineer with the Southern Minerals Corporation, at Corpus Christi, Texas, is now engineer with the Pan American Producing Company, at Charanton, Louisiana.

G. R. HENSON, who has been in charge of drilling and production for the A. G. Oliphant Oil Corporation, at Shreveport, Louisiana, is now manager of the land department of the Sunray Oil Company in Kansas.

FRED B. PLUMMER, of the University of Texas Bureau of Economic Geology, Austin, Texas, spoke on "Origin of Oil Pools," and W. ARMSTRONG PRICE, consulting geologist of Corpus Christi, Texas, spoke on "Importance of Physiography in Military Maneuvers," at a meeting held by the Houston Geological Society, June 18, in memory of DONALD C. BARTON.

ORAN L. PACK, of the Wilshire Oil Company, Inc., Bakersfield, California, has accepted a position as petroleum geologist with Drilling and Exploration Company, Inc., in Salvador, Brazil.

DONALD FRANCIS MACDONALD, since 1932 professor of geology at St. Francis Xavier University, Antigonish, Nova Scotia, died June 1, while engaged in work in the Panama Canal Zone.

JOSEPH HYDE PRATT, State mineralogist of North Carolina from 1897 to 1905, State geologist from 1905 to 1924, died at Chapel Hill, North Carolina, June 2.

S. D. BUTCHER and J. LLOYD CAREY, of Wichita, Kansas, who have been operating under the name of the Rocket Drilling Company, have announced the dissolution of their partnership. Carey's new address will be 610 Orpheum Building and Butcher's, 1306 Union National Bank Building. Butcher will continue drilling and producing operations under the name of the Rocket Drilling Company and Carey will operate individually.

On March 9, under the Production Committee for District 3, as defined by the Office of the Petroleum Coördinator, a subcommittee was organized, to be known as the Committee on Exploration, comprised of SIDNEY A. JUDSON, PHIL F. MARTYN, R. R. MORSE,

ED. W. OWEN, PAUL WEAVER, and F. H. LAHEE, chairman. This Committee on Exploration is a fact-gathering group of men, not representing any particular company, association, or special interests, but serving as representatives of the petroleum industry. The function of the committee is to assemble, as soon as possible, data bearing (1) on the progress of wildcatting (exploration for oil by drilling outside of known producing pools, or below the deepest known pay sands in producing pools); (2) on prospects for petroleum not yet exploited; (3) on methods of exploration to be used in search for new prospects; (4) on the quantity of steel needed in exploring for new prospects; and (5) on the quantity of steel needed for wildcat drilling for oil on new prospects. An early and comprehensive study of these and related data is vital in the program of coördinating the petroleum industry for national defense. Therefore, it is expected that all persons and organizations approached for information toward this end will be ready to coöperate. The committee will welcome any constructive suggestions.

WILLIAM B. HEROY, a past-president of the Association, and president of the Pilgrim Exploration Company, has been appointed director of the division of reserves which succeeds the division of conservation recently headed by E. L. DEGOLYER, who is now assistant deputy coördinator in the Office of Petroleum Coördinator at Washington, D. C.

G. W. CRICKMAY has returned from Nicaragua and may be addressed at Box 549, Athens, Georgia.

W. B. CASE, of the Shell Oil Company, Inc., has moved from New York to Tulsa, Oklahoma.

HOWARD S. BRYANT, division geologist with the Skelly Oil Company at Tulsa, has resigned to become head of the geological and exploratory department of the Hollow Drilling Company at Wichita, Kansas. He is succeeded by WILLIAM W. KEELER, who has been district geologist at Evansville, Indiana. Keeler is succeeded by GEORGE R. WESLEY, who has been assistant geologist at Evansville.

W. T. NIGHTINGALE, chief geologist of the Mountain Fuel Supply Company at Casper, Wyoming, since 1929, and vice-president since 1940, has been elected to the board of directors of the company.

Following the death of its editor, CHARLES ROLLIN KEYES, in May, the last issue of the *Pan-American Geologist* was published in June, 1942, as No. 5 of Vol. 77.

ANNA MINKOFSKY, of New York, has resumed work with the Shell Oil Company, Inc., in the administrative department of the Houston, Texas, office.

The Illinois Mineral Industries Conference, which was scheduled for Urbana, Illinois, October 30 and 31, has been cancelled to support the regional conference of the American Institute of Mining and Metallurgical Engineers, October 1 and 2.

RONALD K. DEFORD, president of the West Texas Geological Society, Midland, Texas, announces the election of new officers of the Society as follows: vice-president, BERNERD A. RAY, Tide Water Associated Oil Company; secretary-treasurer, WILLIAM M. OSBORN, Box 707, consulting geologist.

PHIL D. HELMIG, geologist with the Gulf Oil Corporation, may be addressed at 131 Greer Street, San Antonio, Texas. He is a captain in the Army Air Corps.

JOHN R. FANSHAWE has resigned his position as geologist with the Ohio Oil Company. He expects to join the Army. He may be addressed in care of P. I. Wright, 515 Walnut Street, Erie, Pennsylvania.

J. H. BUEHNER, of the Ohio Oil Company, may be addressed at 515 South 19th Street, Belleville, Illinois. He is in the Air Corps as a second lieutenant.

VERNER JONES, of the Magnolia Petroleum Company at Mattoon, Illinois, is a first lieutenant, Officers Training School, Roney-Plaza Hotel, Miami Beach, Florida.

CHESTER D. WHORTON has been commissioned a lieutenant, senior grade, in the United States Naval Reserve and reported for active duty, July 1, to the Naval Training School, Harvard University, Cambridge, Massachusetts. He may be addressed at D 32, Strause Hall, Harvard University, Cambridge, Massachusetts.

LOUIS DESJARDINS has opened his own office at 739 Kennedy Building, Tulsa, Oklahoma, for consulting service in aero-geologic mapping. Desjardins is a pioneer in the field of geological interpretation of aerial photographs, and structural mapping by this means. He was formerly director of the department of Aero-Geology of Seismograph Service Corporation. The latter organization has discontinued this department and will refer all future business of this type to Desjardins' new office.

FRANKLIN H. SCHOUTEN, formerly district geologist for the Stanolind Oil and Gas Company at Fort Worth, Texas, is in charge of geophysical work, and F. J. SCHEMPF is district geologist.

W. D. HENDERSON, formerly stationed at Amarillo, Texas, has been transferred to Midland as district geologist for the Stanolind Oil and Gas Company.

W. LLOYD HASELTINE, of the Magnolia Petroleum Company, has moved from Midland, Texas, to Wichita Falls, where he is district geologist for the North Texas area.

FRED H. MOORE, of the Magnolia Petroleum Company, has been transferred from Wichita Falls, Texas, to Mount Vernon, Illinois.

W. K. ESGEN, recently vice-president and treasurer of the Trinity Petroleum Company, has been appointed manager of the Gulf Coast Division of the British-American Oil Producing Company.

THOMAS G. PAYNE, of the Kansas Geological Survey, Lawrence, Kansas, has accepted a position with the United States Geological Survey. After 2 months in Alaska, he will return to Kansas to complete his report on the McLouth field, before going to Washington, D. C.

Lieutenant M. HALL TAYLOR, recently stationed at a United States Army post in Texas, is now located "somewhere in the Pacific theater of operations."

NORMAN D. NEWELL, of the geology faculty at the University of Wisconsin, and editor of the *Journal of Paleontology*, has resigned to enter the army. The council of the Society of Economic Paleontologists and Mineralogists has appointed J. MARVIN WELLER, of the Illinois State Geological Survey, Urbana, Illinois, to be the new S.E.P.M. editor of the *Journal*.

IVAN K. NICHOLS has returned from Nicaragua. His address is The Texas Company, New Orleans, Louisiana.

EUGENE M. BAYSINGER, of Lake Charles, Louisiana, has reported at Fort Leonard Wood, Missouri, as a second lieutenant in the Corps of Engineers, United States Army.

ALEXANDER CLARK is with the Shell Exploration Alberta Limited, 302 Bank of Toronto Building, Calgary, Alberta, Canada.

W. A. GORMAN, recently with the Pan American Oil Producing Company, is now geologist and Gulf Coast district manager for the Royal Oil and Gas Company, Esperson Building, Houston, Texas.

WALTER G. MOXEY, of the Stanolind Oil and Gas Company, has been transferred from Midland, Texas, to become district geologist at Amarillo.

BENJAMIN ALVARADO is chief of the Colombia Geological Survey, Bogota.

DEAN A. MCGEE, geologist with the Kerlyn Oil Company, Oklahoma City, Oklahoma, has been elected executive vice-president of the Company, now reorganized as a Kerr-McGee partnership.

JAMES C. TEMPLETON, of the Geophysical Prospecting Company, Ltd., has returned from Trinidad to England, and may be addressed at 6 Neville Court, Abbey Road, London, N.W. 8.

DONALD J. MACNEIL, recently with the McColl-Frontenac Oil Company Limited, Calgary, Canada, is now with The Texas Company, geological department at Mattoon, Illinois.

The Civil Service Commission has recently announced an examination under which Junior Geologists are being recruited. The requirements are: a 4-year college course leading to a bachelor's degree in geology or closely allied science, showing at least 30 semester hours of work in geology which may include graduate study. Applications will be accepted from senior or graduate students who expect to complete the required college course within 6 months of the date of application.

The positions pay $2,000 a year. No written test will be given. All appointments will be for the duration of the War and for no longer than 6 months thereafter. Persons who have received eligible ratings in the option Junior Geologist on the Junior Professional Assistant examination, either No. 193 or No. 221, need not apply for this examination.

Examination announcements and application forms may be obtained at any first- or second-class post office or from the Commission in Washington, D. C. Applications will be accepted until the needs of the service have been met.

ARMY SPECIALIST CORPS[1]

F. L. AURIN[2]
Fort Worth, Texas

Your attention is directed to the statement in the memorandum to the National Service Committee as published in the July *Bulletin* that there is a great demand for Radar work in the Army. This item was discussed under the sub-heading of "Army Specialist Corps."

The purpose of this memorandum is to again call to your attention that such a demand is even greater than anticipated at that time. In fact, the demand is so great that exceptions to the rules must necessarily be invoked so men of all draft classifications and ages can be considered. The same will apply to metallurgists and physicists. Men who have completed college physics and calculus satisfactorily, as well as seismologists, will undoubtedly be eligible for the training course for Radar work. The Army Specialist Corps will be very glad to have applications from men with these qualifications. Many hundreds of First and Second Lieutenants and a lesser number of Captains and Majors will be appointed.

The Army Specialist Corps has established branch offices in the corps areas' headquarters and is coöperating with the Adjutant General's office in establishing others in thirty-five cities. This work is just being organized, and, with the exception of the corps areas' commanders, is not under way as yet.

Those interested in Radar work should communicate with William O. Hotchkiss, Deputy Director of the Army Specialist Corps, Temporary Building "M," Washington, D. C.

Information has just now been received that no additional applications of geologists for "terrain studies" in the Armored Forces should be made at this time, as more than ample applications have been received already to fulfill the requirements. In the event there should be need of additional personnel, this information will be forwarded to you by publication in the *Bulletin*.

A 10-page pamphlet by Dr. Hotchkiss, *The Army Specialist Corps*, printed for distribution by the Geological Society of America, may be obtained *gratis*, by writing to H. R. Aldrich, Secretary, 419 West 117 Street, New York, N. Y., or to A.A.P.G. Headquarters, Box 979, Tulsa, Oklahoma.

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[1] Manuscript received, July 30, 1942.
[2] Temporary chairman, national service committee.

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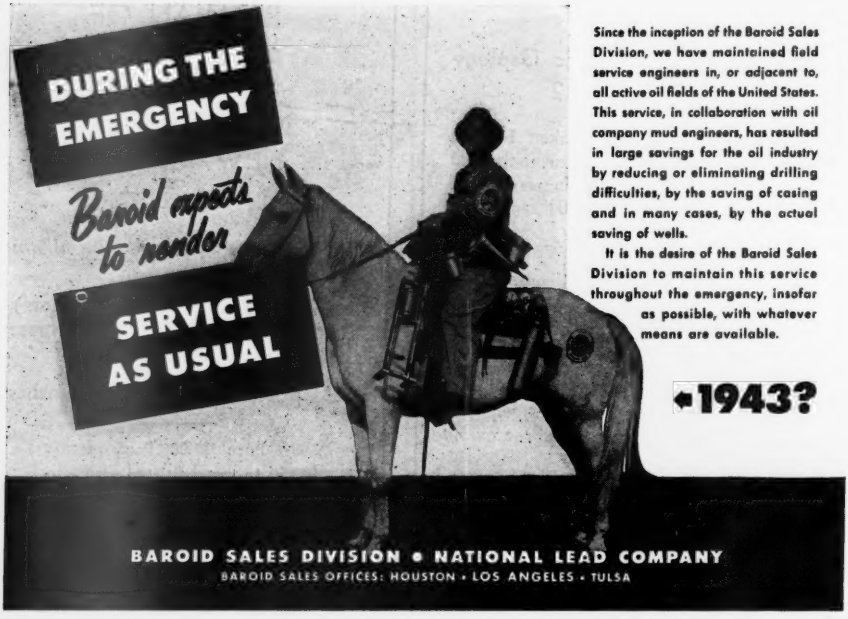
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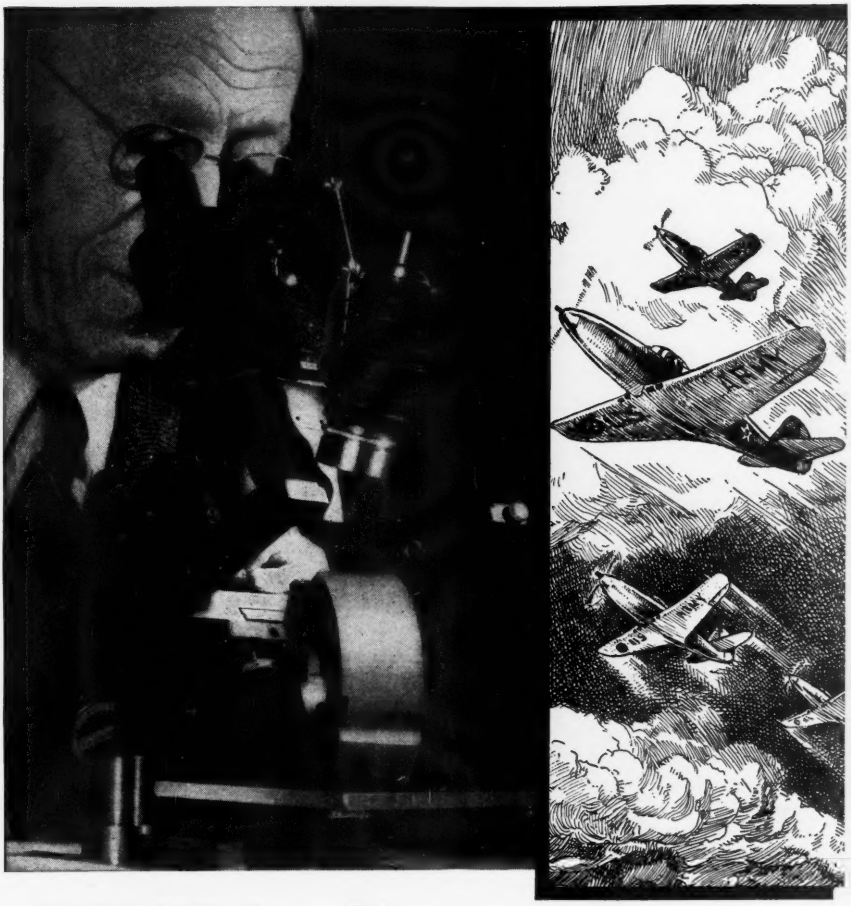

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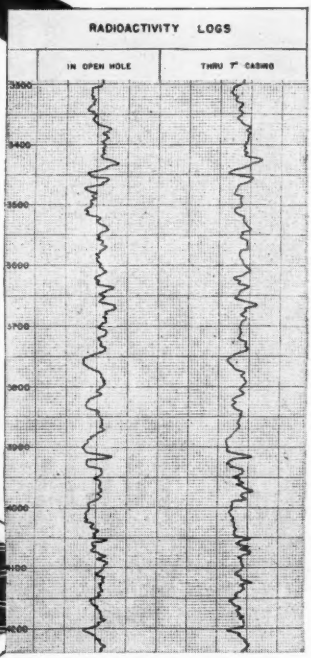

Radioactivity Well Logging provides accurate depth information about formation back of casing in wells where sample logs were made without proper consideration for "sample lag."

Accurate Radioactivity Logs can be made regardless of the nature of the well fluid.

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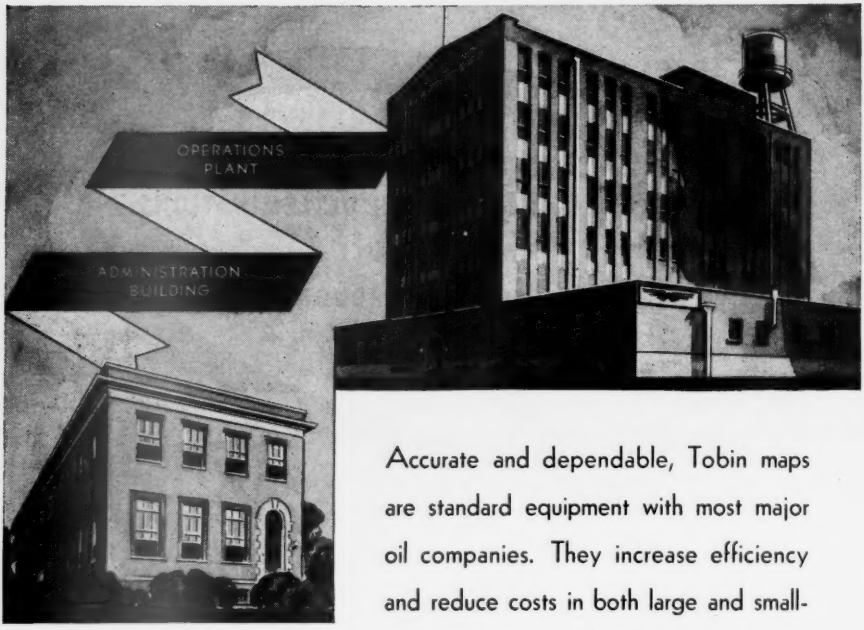

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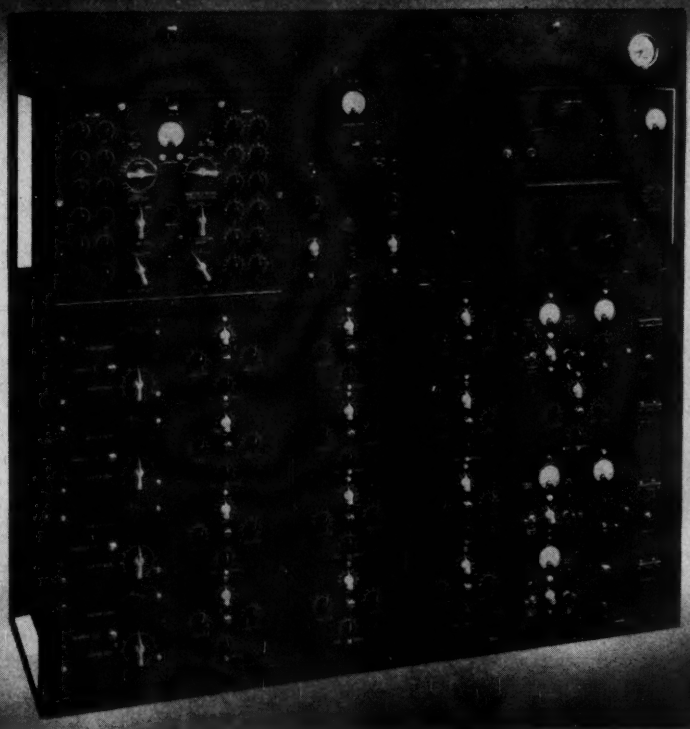

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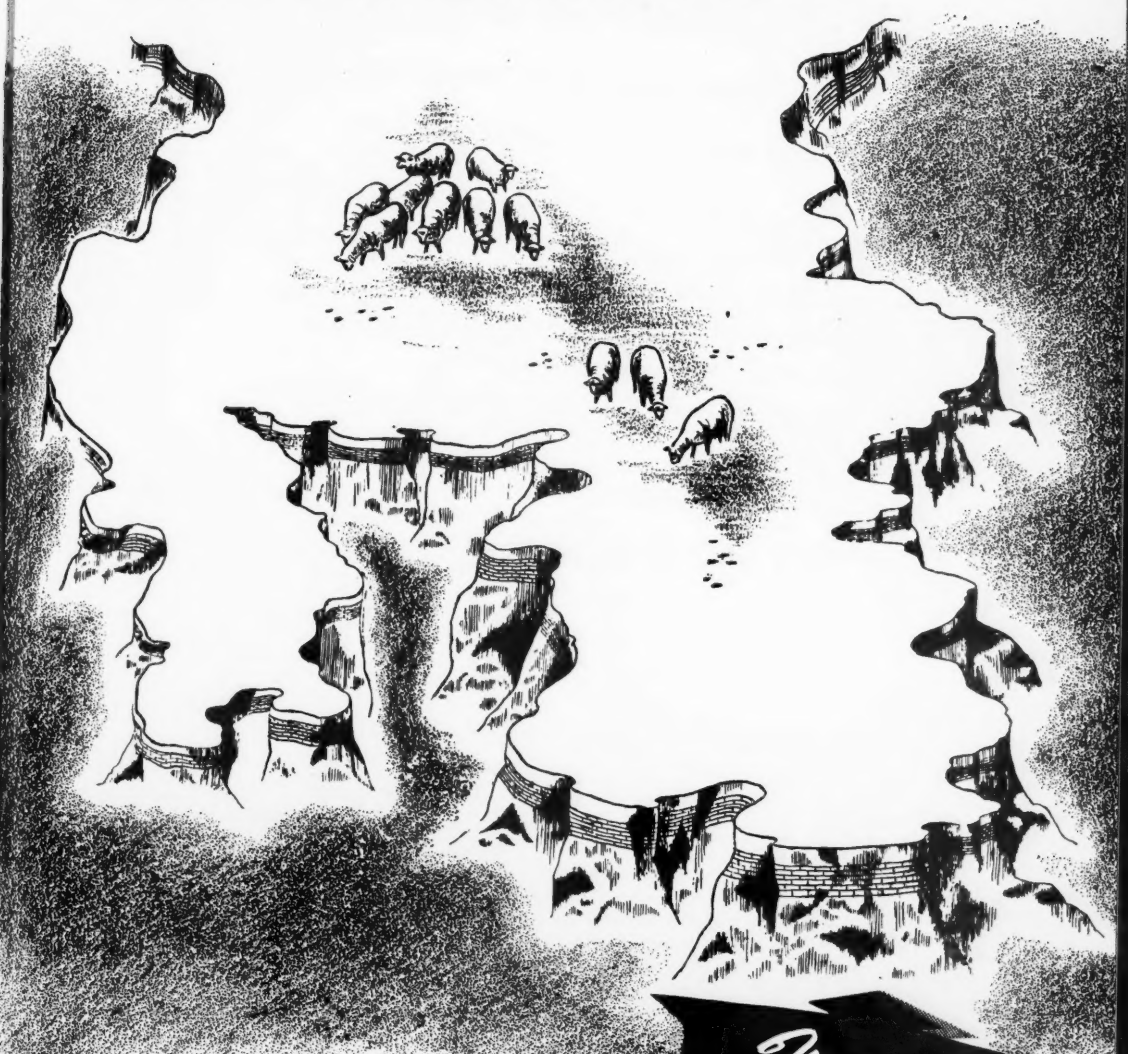

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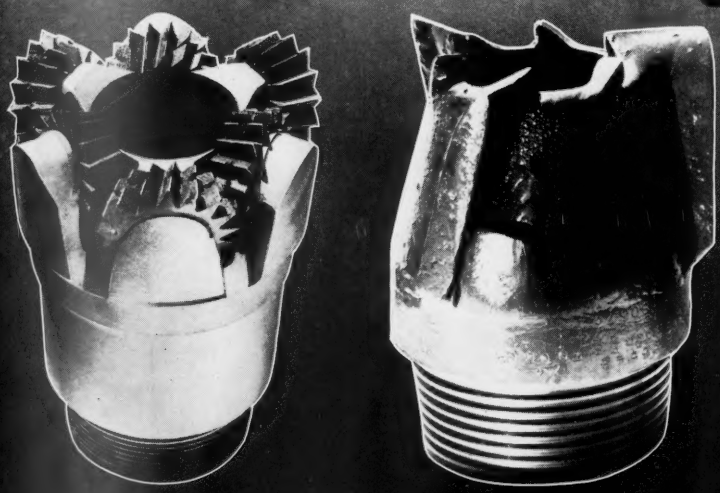

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